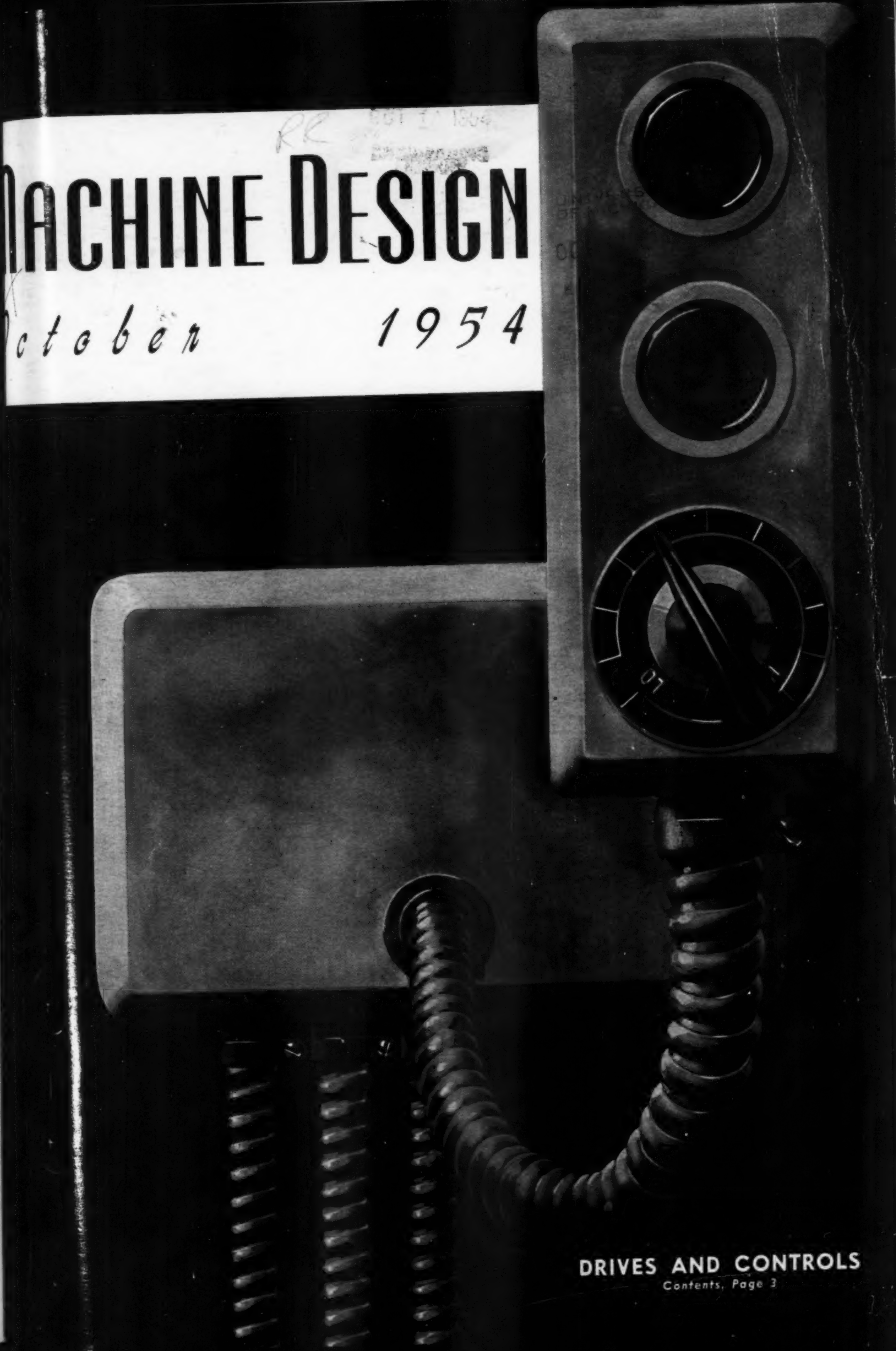
ACHINE DESIGN

ctober 1954



DRIVES AND CONTROLS

Contents, Page 3

THE PROFESSIONAL JOURNAL
FOR ENGINEERS AND DESIGNERS

MACHINE DESIGN

OCTOBER 1954
Vol. 26—No. 10

REGULAR DEPARTMENTS

USE POSTAGE-FREE CARDS FOR:

Over the Board

Mechanism of the Month Club

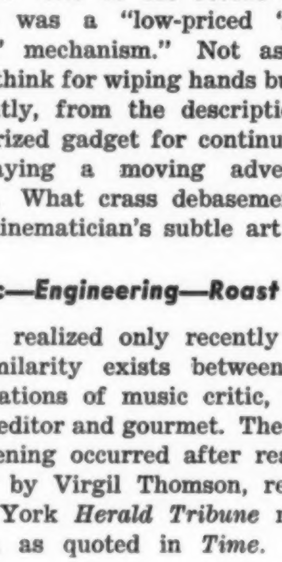
To those perennial joiners who haven't yet attained the distinction of becoming a member of the Caterpillar Club, Explorers Club or the Little Men's Chowder and Marching Society, we'd like to suggest another possibility—the Mechanism of the Month Club. The MoM Club, sponsored by Gale Dorothea Mechanisms Inc., offers its members a monthly "mechanism selection," probably on the theory that busy hands make happy hearts. One of the recent selections was a "low-priced 'roller towel' mechanism." Not as you may think for wiping hands but apparently, from the description, a motorized gadget for continuously displaying a moving advertisement. What crass debasement of the kinematician's subtle art!

Music—Engineering—Roast Beef

We realized only recently that a similarity exists between the occupations of music critic, technical editor and gourmet. The rude awakening occurred after reading a bit by Virgil Thomson, retired New York *Herald Tribune* music critic, as quoted in *Time*. Said Thomson, "Unusual works have more news value than Toscanini . . . There is great validity in the constant performance of classical music, but the real news is deviation from the routine. For instance, I might be very fond of roast beef, but as food editor, I would find it exceedingly difficult to write very many interesting articles about the taste of roast beef." As editors we can appreciate Thomson's comment — but also must admit that we're fond of roast beef. That's why we'll always try to provide a toothsome bit of meat in our article menu, as well as a tasty selection of unusual and interesting news items and ideas.

This Month's Cover

Very often a subject that seems simple from a first view requires a lot of explanation—particularly in engineering. For instance, take this month's front cover by George Farnsworth. As you've probably guessed, it's a typical electric adjustable-speed drive setup: speed controller, power unit, and motor. All you do is set the desired speed, punch the button, and you're off to the races. Of course, the subject is actually a whole lot more complicated. And a good idea of the engineering factors involved can be gained from Bob Rodgers' article, "Adjustable-Speed Electric-Motor Drives," on Page 185.



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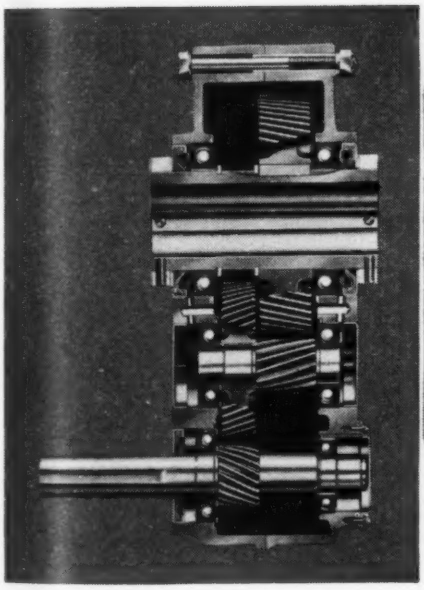
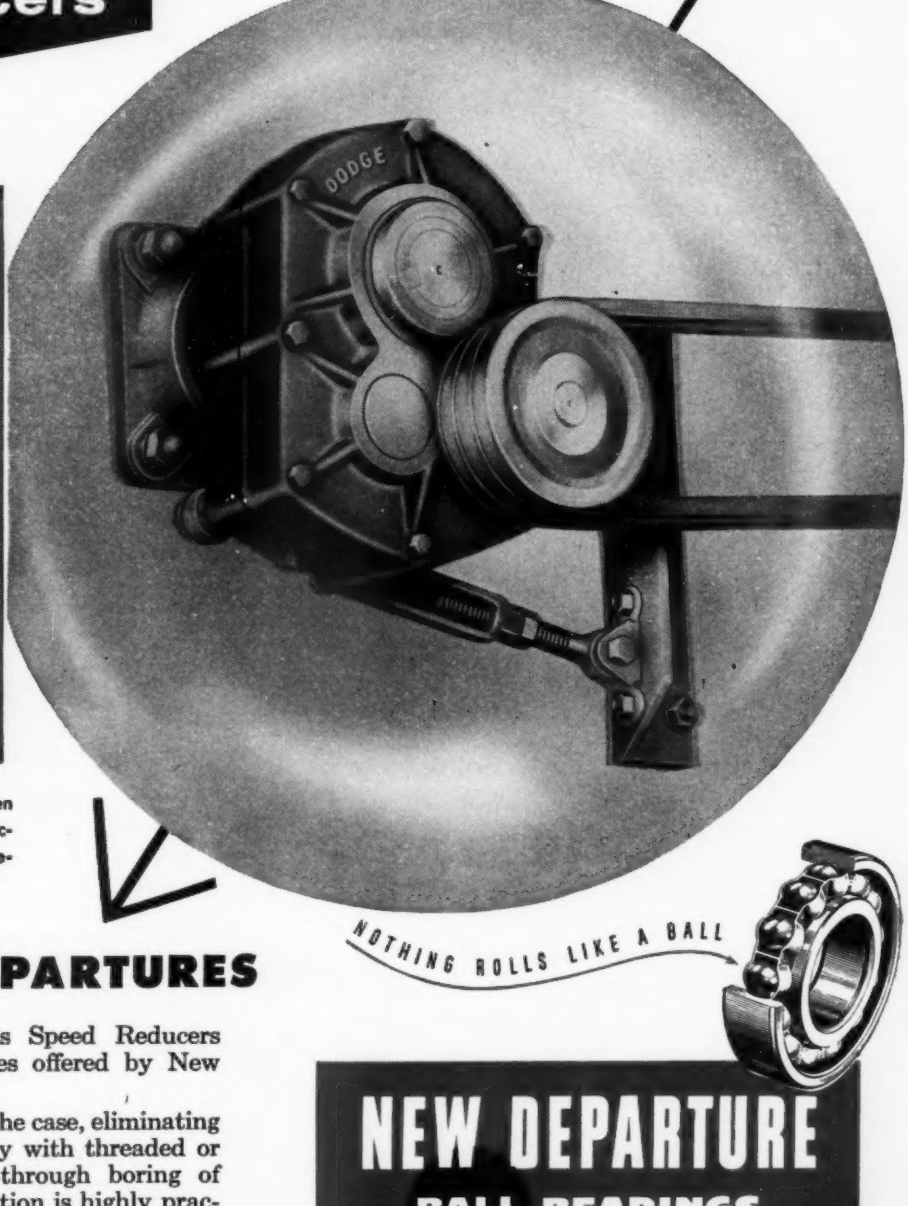
BPA NBP

Reducing Costs in Speed Reducers





New Departure **ball** bearings are used in seven basic sizes of the Dodge single and double reduction speed reducers, handling from 1 to 43 horsepower at output speeds from 12 to 330 r.p.m.

NOTHING ROLLS LIKE A BALL

... with NEW DEPARTURES

Dodge Manufacturing Corporation's Speed Reducers make good use of design advantages offered by New Departure snap-ring **ball** bearings.

The snap rings locate the bearings in the case, eliminating the need for adjustment. Doing away with threaded or shim-type devices permits straight-through boring of the housing. Thus split-case construction is highly practical, and assembly is greatly simplified. The result is a rigid, highly efficient unit, and one in which production costs have been kept to the minimum.

Learn what New Departure can do for *your* product. Talk with your New Departure sales engineer—*today!*

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Engineering News Roundup

Carbon-Steel Castings Minimum Standards Proposed

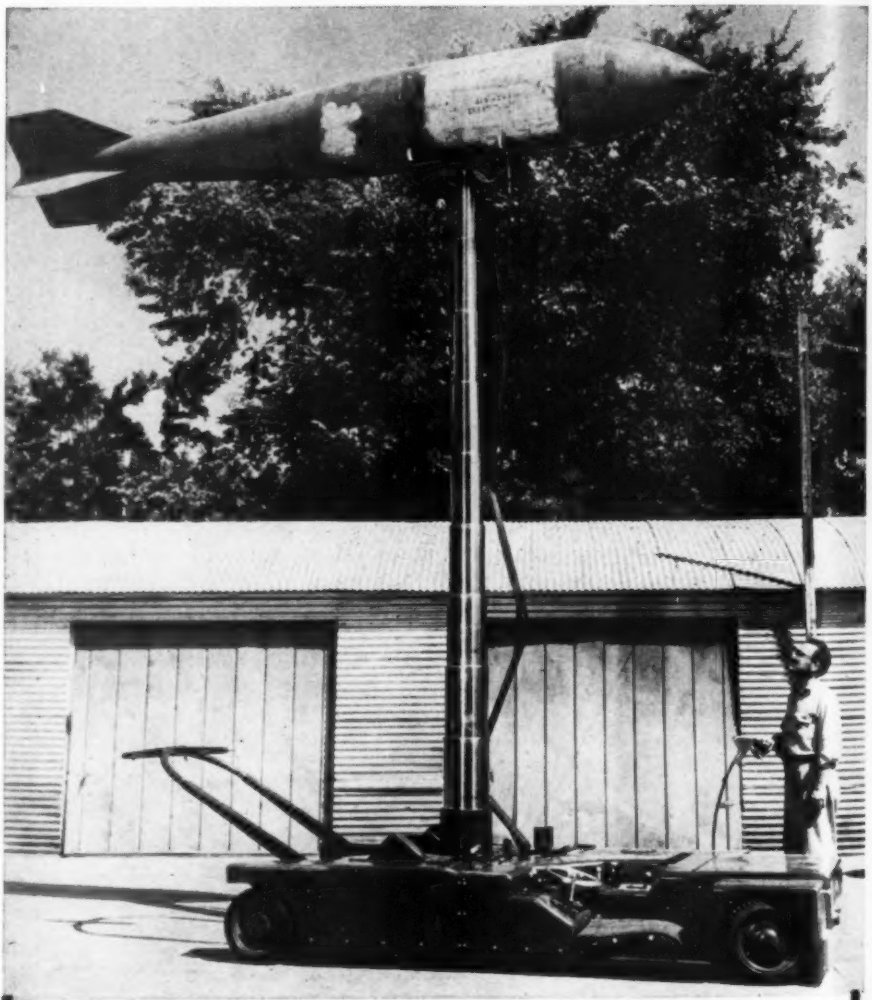
New suggested minimum standard for commercial carbon-steel castings has been announced. Adopted by the Steel Founders' Society of America, the new standard is said to present foundrymen with a workable minimum specification.

Commercial carbon-steel castings representing readily weldable materials are covered by the proposed standard. Specifications, according to the Society, are not meant to replace other specifications now in use. Rather they are a practical approach to the fuller use of properties inherent to cast carbon and low-alloy steel.

Greater latitude possible in steel casting production by using the proposed standards is shown by comparison with the American Society for Testing Materials specification A27-52T. The ASTM standard specifies a maximum percentage of chemical elements for each of several grades, each grade having its own minimum tensile strength and yield point. The proposed Steel Founders' standard lists one table of maximum percentages of composition. Similarly, there is only one mechanical property minimum. Thus, foundries have greater flexibility in choosing chemical composition.

Riser and gate finishing, heat treatment, repair of defects and methods of inspection and testing are also covered in the recommended standard.

According to the Steel Founders' Society, several foundries have adopted the recommended minimum standard. Use of the standard is to be a matter of voluntary agreement between the foundry supplying the steel casting and the buyer. The Society emphasizes that improvements on these suggested minimums are not to be influenced by the proposed standard. These specifications are expected to be used only where no



GOING UP: Self-contained, motorized bomb lift pictured here is reported capable of easily handling bombs up to 4000 pounds. Designed and built by Standard Mfg. Co. of Dallas, the mechanism can rise to approximately 15 feet on its 9-section telescopic hydraulic ram. Two double-enveloping Cone-Drive gear sets power accessories to the lift. One drives a winch to drag the bombs from storage to the lift; the other powers the lift arms that raise the bomb from the ground onto the ram

tubing shapes up like this at OSTUCO

We start with these basic shapes . . . then we forge and fabricate carbon and alloy steel tubing to your exact specifications all under one roof. One purchase order takes care of all details. If you would like to know more about our "single source service," send for our newest catalog, "OSTUCO Tubing" . . . better yet, send your blueprints for prompt quotation.

OSTUCO SHELBY, OHIO **OSTUCO TUBING**

SEAMLESS AND ELECTRIC WELDED STEEL TUBING
—Fabricating and Forging

OHIO SEAMLESS TUBE DIVISION
of Copperweld Steel Company • **SHELBY, OHIO**
Birthplace of the Seamless Steel Tube Industry in America

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CANADA, RAILWAY & POWER CORP., LTD.

EXPORT: COPPERWELD STEEL INTERNATIONAL COMPANY
117 Liberty Street, New York 6, New York

customer specification calling for a different quality level appears on an order.

Copies of the recommended standards are available free by writing to the Steel Founders' Society of America, 920 Midland Bldg., Cleveland 15, Ohio.

Size comparison of the Sno-Buggy with a standard jeep. Behind the operator's cab is the 400-hp engine-generator and the 580-gallon fuel tank

Giant Jeep Designed To Go Almost Anywhere

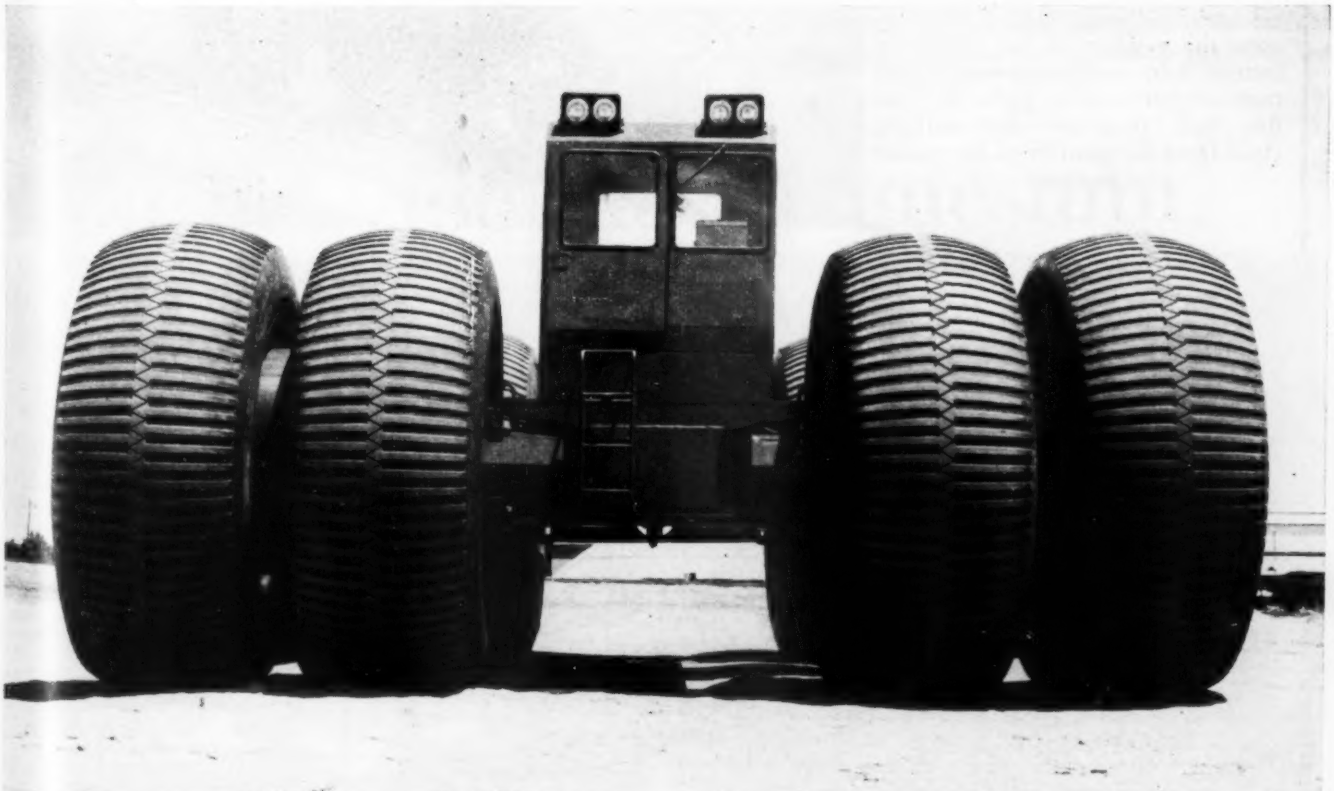
Exploration of swamps, deserts, deep snow or any type of unstable terrain is said possible with a new 23-ton vehicle. Called the Sno-Buggy, the machine was designed by R. G. LeTourneau Inc. for use where transportation by ordinary land vehicles, boats or aircraft may be difficult or impossible.

Eight tires made by Firestone, each 10 feet high by 4 feet wide, support the machine. Tire air pressure may vary from 4 to 25 psi depending upon the weight being carried. Weight can be added for ground gripping or reduced for flotation.

Four electrically-driven wheels power the Buggy at speeds of about 8 mph forward or backward. Each wheel has its own electric drive motor powered by a generator driven with a 400-horsepower engine. Fuel for the generator engine may be gasoline, diesel oil or liquefied petroleum gas.

All operations, including steering, are electrically controlled by small switches. Method of braking is a regenerative electric system. For emergency stops and parking, spring-loaded bimetallic friction brakes set automatically when the electric drive motors are turned off.

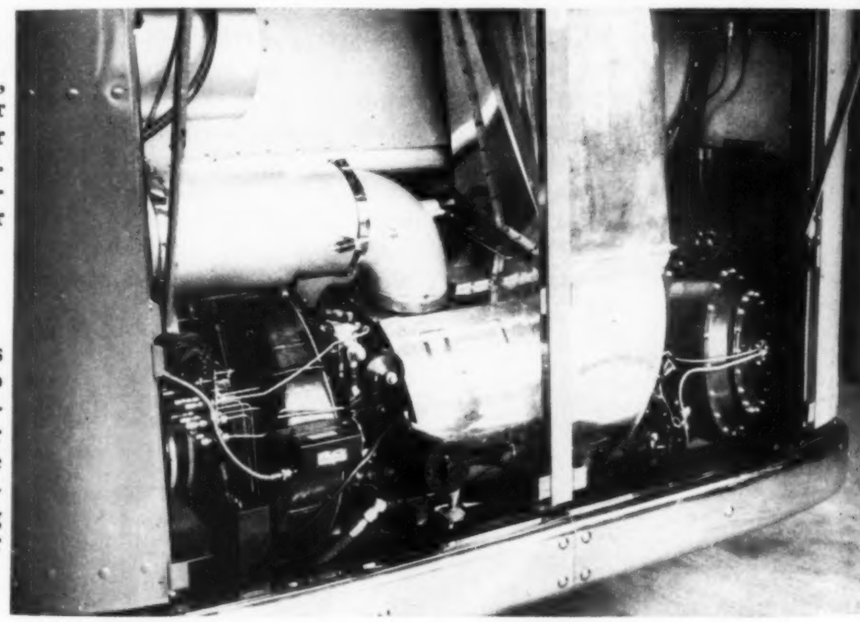
Overall width of the Sno-Buggy is 24 feet. Overall length is $27\frac{1}{2}$ feet and ground clearance is $3\frac{1}{2}$ feet. Outer tires may be removed, reducing the width to 15 feet if desired.



Head-on view of the new LeTourneau Sno-Buggy designed to travel across deep snow, soft sand or muddy swamps. Each of the tires is 10 feet high and 4 feet wide. Total width of the vehicle as shown is 24 feet

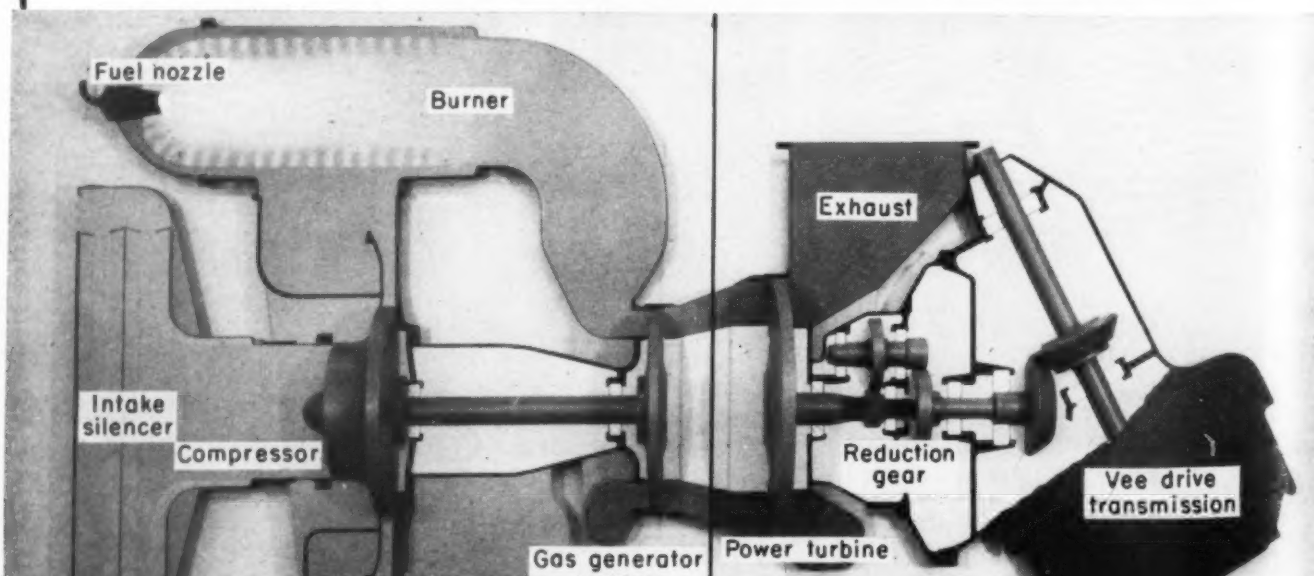
Newly developed, a 300-horsepower gas turbine is being tested for passenger buses. Called a Whirlfire Turbo-Power unit, the engine has been installed by General Motors in a GMC transit coach.

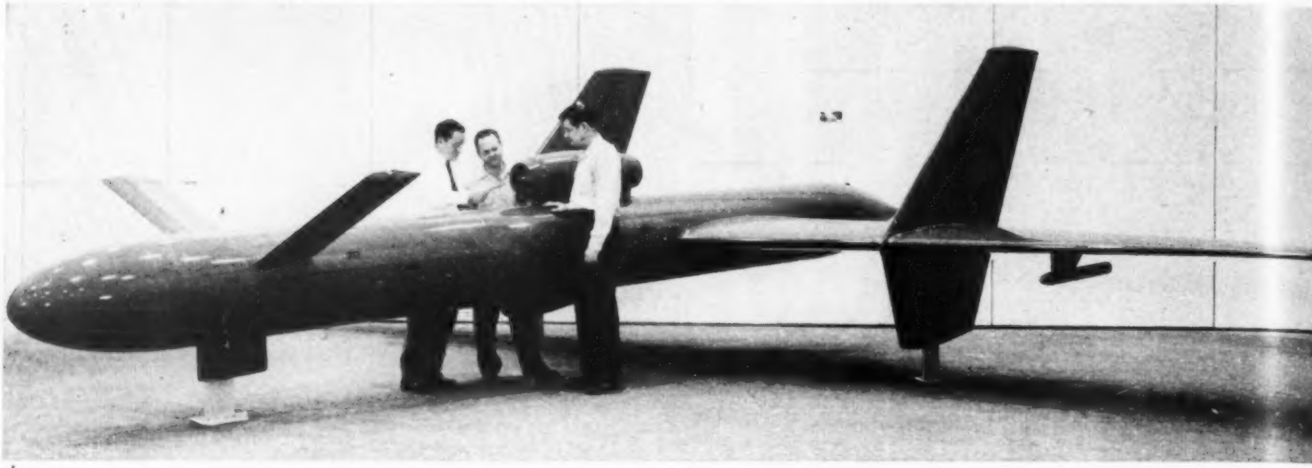
Notable difference in outward appearance of the bus is the absence of rear windows and the exhaust stack discharging through the rear roof panel. Driver's controls are conventional



Closeup of the engine installation, right, shows the gasifier-compressor at the left and the single combustor above it. Exhaust duct is at the right. A portion of the Vee-drive transmission housing can be seen to the far right

New General Motor's GT-300 gas turbine, below, is made up of two mechanically independent components, the gasifier or gas generator section, left, and the power-turbine transmission section, right. A flexible duct transmits the working fluid from the gasifier to the power turbine



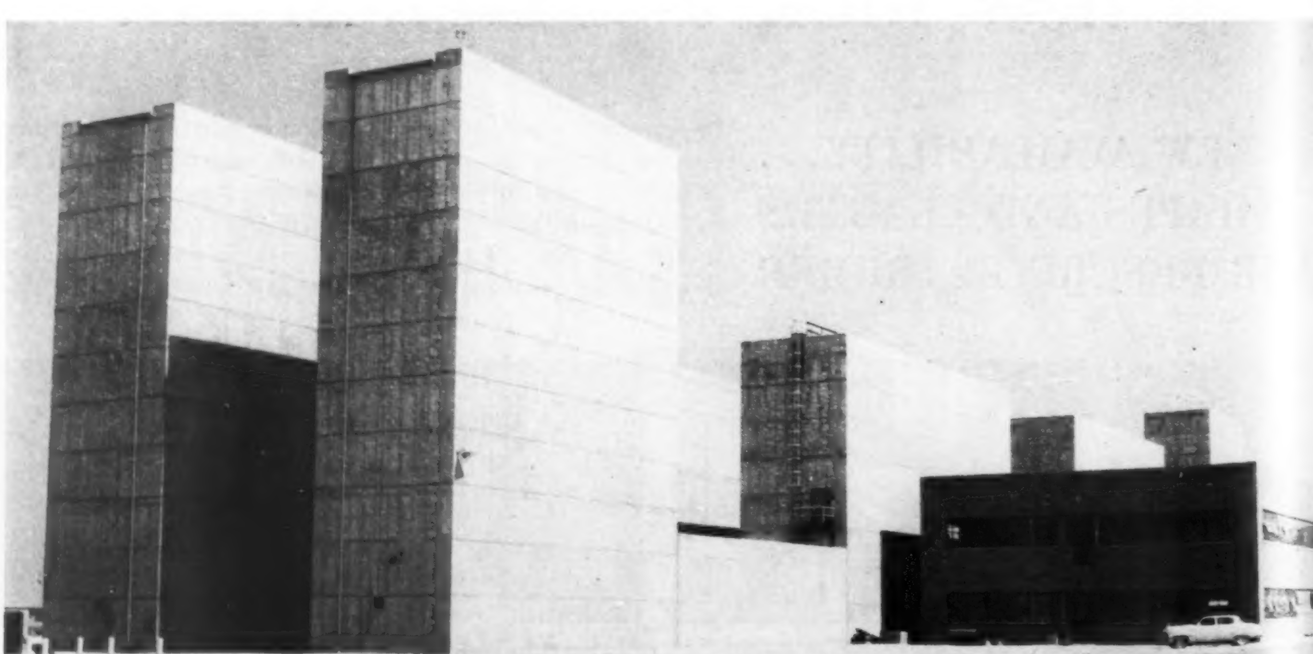


FAIR GAME is this realistic winged tow target for jet fighter gunnery practice. Weighing 1400 pounds, the target has a 25-foot wing span and may be towed as far as 2 miles behind the tow plane. Because of its design, the all-metal target may be towed at speeds in excess of 500 mph. It can be made to maneuver either automatically or by direct control from the tow plane. On landing, a parachute slows the target to a stop when the tow cable is released

Giant Test Cells Tame Jet Engine Noise

Quieting the roar produced by jet engines is successfully accomplished by these six test cells, each about as high as a seven-story building. Covering about 100,000 square feet, the cells are located at Ford Motor Company's aircraft engine plant in Chicago. When in operation they are said to eliminate engine noise beyond 100 feet from the testing area.

Designed by Armour Research Foundation, the test facility includes control rooms, office, laboratories and storage sections. Each cell consists of air intake ducts 20 feet by 20 feet feeding 350,000 cubic feet of air per minute. Cooling of exhaust from 3000 to about 400 F is accomplished by passing exhaust gases through an air tube buried in the earth and by mixing them with water. An exhaust section is made of 1-foot thick concrete lined with 3 inches of sound-absorbing mineral wool. Sound waves are channeled through a series of 180-degree turns which reduce their intensity to about one-millionth of the original value.



Steel Center Shifts Six Miles

In the category of handy information to have around is the location of the steel-making capacity center of the United States.

Beaverdam, in Allen County, Ohio, was the geographical center in 1952. During the past two years, according to the American Iron and Steel Institute, the center has moved about 6 miles south. In 1951, the geographical center was at Mt. Corey, Ohio, about 10 miles northeast of the present center. Beaverdam, Ohio, is about 60 miles southwest of Toledo and has no steel mill of its own.

The steel industry now consists of 255 companies having 430 plants in 31 states. Total area covered by these plants is said to be over 80 square miles.

Pennsylvania, Ohio, Indiana and Illinois are the leading states in hot-rolled steel capacity. Among the states that have advanced in rank in the past three years are New York, now in sixth place, and Texas, now in eleventh place. During the past three years, Pennsylvania had the largest increase, followed by Ohio and Indiana.

Nebraska, which was not on the steel map a few years ago, has acquired steel finishing capacity without becoming an ingot maker or a hot-rolled steel producer. Texas now leads in capacity for making electric-weld pipe, while Pennsylvania is the leading state in butt-weld pipe capacity.

National steel making capacity, reported by AISI, increased nearly 16 million tons from the start of 1952 to 124.3 million tons a year at the beginning of 1954.

GIANT SPINNING LATHE spins a 14-foot dome for air-conditioning equipment. Said to be one of the worlds largest, it can spin shapes up to 180 inches. Hydraulically controlled, the lathe was built by Pheonix Products Co. of Milwaukee and is powered with a 50-horsepower motor. Speed, clutches, brakes, and all movements of the tailstock are controlled from a portable control panel. Aluminum up to $3/4$-inch thick may be spun to a depth of 72 inches

Westinghouse Electric Corp. recently broke ground for its new metals plant at Blairsville, Pa. When completed, the plant will bridge the gap between research and the commercial application of metals and alloys in the electrical industry. It will work closely with the new Westinghouse Research Center in the development and application of new metals.

Copper Survey Says We Have Enough

First of a new series of quarterly reviews of the copper industry issued by the Copper Div., Business and Defense Services Administration, indicates that copper "is fortunately in ample supply to meet any foreseeable demand."

According to William A. Meissner, Jr., deputy director of the Copper Division of BDSA, all three sources of domestic supply are improving. He reports that mine production, net imports, and scrap all show promise of substantial increases in both the short and the long-term views.

This first quarterly survey deals mainly with prospective copper supplies during 1954. Tables and charts were compiled from data supplied by the Bureau of the Cen-

(Continued on Page 24)

Over 1,000,000

OVER A MILLION families wash their clothes in Laundromats. Westinghouse also does a big export business, so these machines have to be trouble-free.

HERE, a man installs the main suspension springs. The springs are periodically tested to meet severe 450 c.p.m./⅝-inch amplitude, vibration tests.

AS UNIT IS INSTALLED in shell, man holds top damper spring. Notice damping blocks on end of flat spring to reduce excess movement.

Laundromats in use, but...

"We've never had a failure with American Quality Springs"

says WESTINGHOUSE ELECTRIC CORPORATION

The Westinghouse Laundromat has been a household word ever since the first unit rolled off the production line in 1940. Since then, Westinghouse has produced over 1,125,000 Laundromats. Despite many important improvements, the superb spring suspension system has stood the test of time. It's the same today as it was in 1940, because it was designed so well in the first place.

Three different styles of American Quality Springs are used in the Laundromat. The *coil* springs support the entire weight of the machine within its shell. The *flat* steel springs contain friction dampers that limit excessive movement caused by an unbalanced load during the spin-dry cycle.

Failure of a coil spring could damage the entire machine. At the least, it would mean an expensive service call. But, because of the efficient design, and the completely reliable American Quality Springs, *no spring has ever failed in a Westinghouse Laundromat.*

If service like this makes sense to you, get in touch with your nearest American Steel & Wire representative. We make all kinds of springs, any steel, any finish. And you'll get the same kind of quality that Westinghouse gets.

AMERICAN STEEL & WIRE DIVISION, UNITED STATES STEEL CORPORATION, GENERAL OFFICES: CLEVELAND, OHIO
COLUMBIA-GENEVA STEEL DIVISION, SAN FRANCISCO, PACIFIC COAST DISTRIBUTORS
TENNESSEE COAL & IRON DIVISION, FAIRFIELD, ALA., SOUTHERN DISTRIBUTORS • UNITED STATES STEEL EXPORT COMPANY, NEW YORK

U·S·S American Quality Springs

UNITED STATES STEEL

BOTTOM DAMPER springs are installed. Because of the entire engineered suspension, Laundromat was one of the first washers that didn't have to be bolted to floor.

WESTINGHOUSE LAYS DOWN rigid specifications for their American Quality Springs, proving their motto, "Quality must be *built* into a product."

(Continued from Page 21)
sus, Department of Commerce, Bureau of Mines, Department of the Interior and other sources. A future publication will deal with long range expectations.

Brush Electronics Co. has announced its further expansion in the electronics field with the purchase of the Digital Instrument Co. Electronic counters formerly manufactured by Digital will be integrated into the Brush line, Brush president W. R. Burwell, announced. M. C. Burns, former Digital president, will serve as manager of Brush's new Digital Instrument Dept.

Cabinet Committee Will Study Engineer Training

A Cabinet committee on the training of scientists and engineers has been appointed by President Eisenhower. The committee, according to the *Engineering and Scientific Manpower Newsletter,* includes the secretaries of Commerce, of Labor, and of Health, Education, and Welfare, the Assistant Secretary of Defense for Manpower, the directors of the Atomic Energy Commission, of the National Science Foundation, and of the Office of Defense Mobilization.

Realization of the rapid advances in Soviet science and technology, and of the phenomenal growth of Russia's manpower pool of engineers, scientists, and technicians, in contrast with the shrinkage of our professional output, was an important factor in prompting Presidential action. The committee will learn, says the *Newsletter,* that the tide of diminishing student enrollments has turned in certain fields, although the number of graduates has continued to decline, reaching its low of 19,000 in engineering this year. The upturn in chemistry is not expected for an-

MIRROR TURBINE is the heart of this high speed camera, capable of producing up to 2.4 million high-resolution photographs per second. Images are focused on a stainless or alloy-steel turbine-mirror through a highly corrected 24-inch achromatic lens and relayed to the film through an appropriate optical system. Helium drives the turbine at speeds up to 10,000 rpm. Made by Beckman and Whitley, the camera is expected to fulfill needs of research workers in the fields of combustion, corona discharge, explosion, shock-wave phenomena, and plastic deformation

other year or two, and then only at the B. A. level. In mining engineering, the earth sciences, ceramics and physics, enrollments are still low, with no improvement in prospect. And in no field is the improvement enough to take care of cumulative deficiencies.

MINIATURE COAXIAL RESISTORS have been specially designed for application as coaxial-cable termination resistors by Hanson Electronics of Los Angeles. Replacing the familiar $1/2$-watt tubular resistor, the new units may be used in miniature electronics equipment where improved frequency response is desired. Made by the same process used for manufacturing tape resistors used in printed circuits, they are lightweight and will withstand high heat

Face Increased Demand For Synthetic Lubricants

Over 1.7 million gallons of synthetic lubricants for jet engines will be required during the next three fiscal years, announced Thomas P. Pike, assistant secretary of defense, recently. Demand will also increase substantially in the years beyond 1957, he stated.

Consumption applies to synthetic lubricants of a quality suitable for high-thrust jet engines to power the latest jet bombers, fighters and interceptors. Future high-performance military and commercial jet aircraft are expected to use these lubricants in gas turbine engines.

Mr. Pike indicated that the an-

nouncement of current and future military requirements was being made to point up the need for expansion in the field of synthetic lubricants in order to meet future requirements.

• • • VIDIGAGE *combines an ultrasonic generator and a 21-inch television tube to measure thickness and detect laminar flaws nondestructively from one side of the piece being measured. Bright lines projected on the TV tube screen indicate thickness of the piece being measured, which may be read directly from scales on the tube. Ultrasonic waves generated by the device cause the piece being measured to resonate at a frequency dependent on its thickness, and the bright lines on the screen indicate this dimension. Range of the Vidigage is from* 0.0012 *to* 2.5 *inches with accuracy of* 0.1 *per cent. Greater thickness can be calculated.*

New Alloy May Make Good Steel Substitute

A lightweight titanium alloy considered suitable as a replacement for steel in military weapons has been developed for the Ordnance Corps by Armour Research Foundation of Illinois Institute of Technology.

About 40 per cent lighter than high-strength steel, the alloy will greatly increase mobility of heavy weapons and tanks. Tests have shown that the alloy is highly corrosion resistant and has properties comparing favorably with the steel used in making weapons.

Tensile strengths up to 192,000 psi have been shown, which is about 42,000 psi stronger than any commercial titanium alloy now manufactured.

Although the tests are not yet conclusive, Ordnance officials consider the alloy as a potential substitute for steel in many ordnance components.

Eighth New England Conference on Quality Control will feature a group of seminar discussions. An-

News Roundup

nounced by the American Society for Quality Control, the seminars will take place on October 22, the second day of the three-day meeting. Managing of the quality control function will be discussed during three six-hour sessions. Organizing a defect-prevention program, supervision of an inspection department, customer relations, and staffing and budgeting are a few of the subjects to be considered. Details of the seminars as well as the entire conference may be obtained by writing to American Society of Quality Control, Box 1681, Southern Connecticut Section, Bridgeport 1, Conn.

Aircraft Structure Data Will Be Summarized

Unrelated and unco-ordinated results of a vast amount of recent research on aircraft structural strength will be summarized and digested in a new aircraft structures encyclopedia to be written by New York University aeronautical engineers. The new encyclopedia is expected to make possible more effective use of engineering manpower in a field with a large turnover rate.

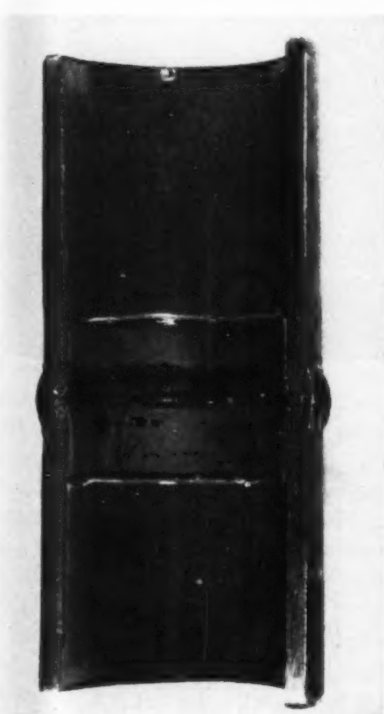
According to spokesmen for the aircraft industry, summaries of the structural research done at various universities, by the NACA and test data from aircraft companies are badly needed. A great num-

ber of relatively inexperienced engineers, it has been noted, are currently designing airplanes, and the turnover rate among aeronautical engineers is about 30 per cent a year. The summaries will enable these engineers to locate design methods or test data on a specific problem more quickly.

New Method for Joining Porcelain Enamel Lined Pipe

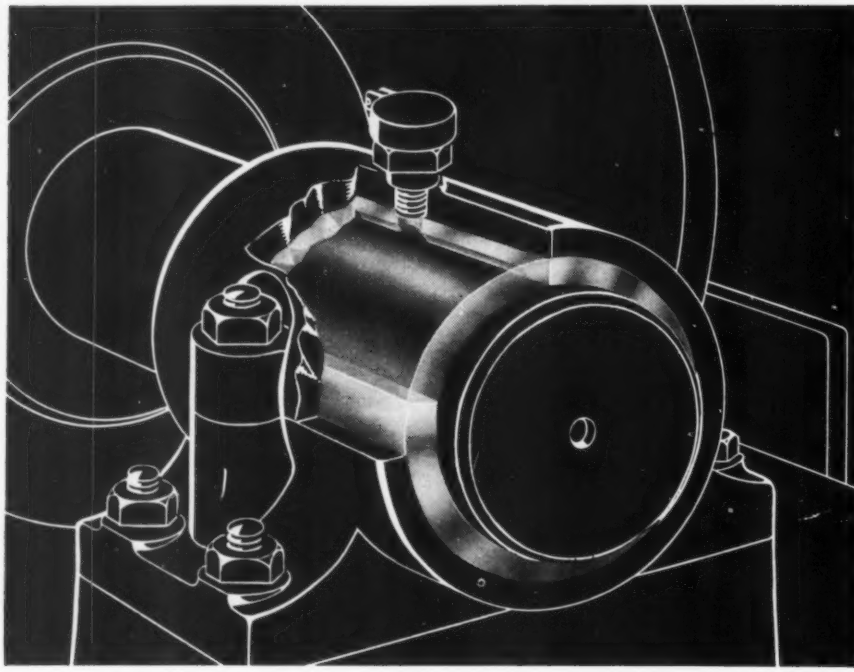
Maintaining the effectiveness of the porcelain-enamel lining of pipe is difficult using standard methods of joining, according to the Barrows Porcelain Enamel Co. In order to eliminate expensive prefabrication in installation, the company has developed a new method by which joining can be accomplished in the field.

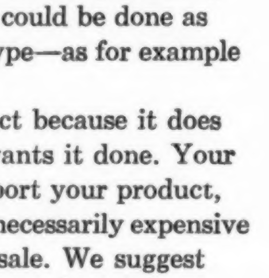
Porcelain-enamel coated inserts of light-gage metal are placed in



Porcelain - enamel lined pipe weld shown above illustrates how the glass coating of the insert is fused to the glass lining of the pipe

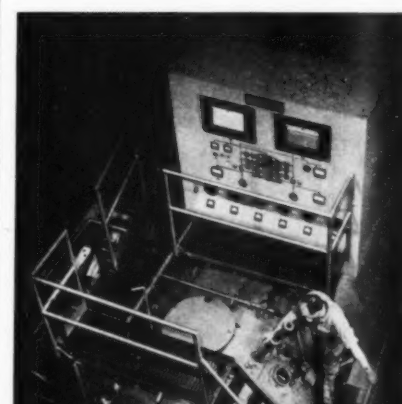
each of the pieces of pipe to be joined. Ends of the pipe are brought together and welded with an oxyacetylene weld. Since the





heat of the welding operation fuses the glass coating of the insert to the glass lining of the pipe, corrosive liquids cannot reach the steel base metal. It is claimed that a good pipe welder will require very little more time with this method than for welding ordinary pipe.

This type of piping is said to be useful where pipe may be subject to corrosion and in processes where a catalyst is contaminated by contact with certain metals. New applications at lower cost where high temperatures are used are expected to be found.



ONE-HALF TON CAPACITY vacuum furnace for melting and centrifugally casting high-temperature alloys is said to be the world's largest. Built by F. J. Stokes Machine Co. for Utica Drop Forge and Tool Corp., the furnace will be used to make high-purity alloys of superior heat-resisting properties for use in turbine blades and disks of jet engines

AGMA Index for July, 1954, shows an increase of 10.9 per cent compared to June, 1954. June figure was 127.4. April, 1954, figure was 158.2, dropping to 134.2 for

May. AGMA index figures are computed from a base figure of 100 which represents the 1947 to 1949 period.

"Well, back to the drawing board . . ."

Giant Shovel Will Scoop 100 Tons

Said to be the biggest land vehicle in the world, a new all-electric stripping shovel is being built by Marion Power Shovel Co.

To be electrically powered by 14 General Electric motors developing a maximum of over 7500 hp, the shovel is expected to handle nearly 100 tons of rock and earth at each pass. Boom of the shovel is 150 feet long and is said to be larger than any previously built. As high as a 12-story building, the machine is claimed to be the largest land vehicle in the world.

Electric power will be transmitted to the shovel from a portable 5000-kva substation. Two motor-generator sets will supply dc power. One will be driven by a G-E 3500-hp, 3500-kva, 1200-rpm synchronous motor. This will drive four 400-kw hoist generators plus one 330-kw crowd generator. The other motor-generator set will consist of a 1000-hp synchronous motor driving two 330-kw dc generators for supplying power to four swing

motors. Hoist motion will be powered by four 450-hp motors. There will be four vertical-swing motors totalling 750-hp and two crowd motors each 187½ hp.

The control equipment will involve an amplistat-amplidyne combination for each of the three motions to give maximum control of acceleration, overshooting and plugging with flexibility and ease of operation. Amplidyne motor field control equipment will be used with the 3500-hp synchronous motor to help maintain pull-out torque and improve line voltage conditions under heavy loads.

Another feature, setting the new shovel apart from its predecessors, is the independent propel or traction drive utilizing four 250-hp, wound-rotor induction motors and special steering control. These features permit ease of handling.

This shovel is so large, Marion engineers report, that an office building type elevator is being built to carry 1,000 pounds or three passengers up to the control section.

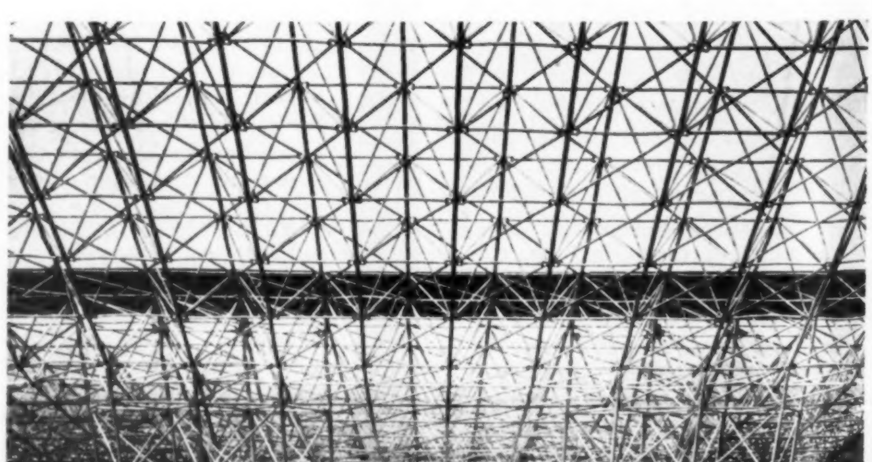
King-Size Jungle Gym Makes Airplane Hanger

Made of tubing and connectors, a proposed dismountable airplane hangar has been developed for the U. S. Air Force. Based on a double cantilever design and "space frame" principles developed at Illinois Institute of Technology, the structure is expected to house six B-36 bombers for maintenance or eight for storage.

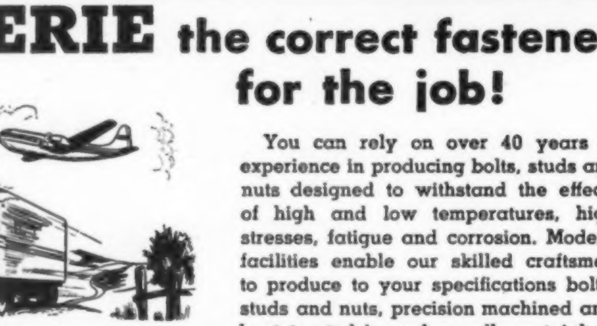
Standardization of parts and simplicity of connections is expected to make fast construction possible with unskilled labor. Tubes joined with a new type connector make up a web-like shape out of a series of pyramids.

A distance of 10 feet from center to center of all the units in all directions provides a basic dimen-

(*Continued on Page* 38)



Model of the newly developed airplane hangar construction design showing the 3-D triangular units making up the frame. Pyramid-type structures will support the roof



News Roundup

(*Continued from Page* 32)

sional relationship between the units. All parts are interchangeable and there are said to be no key points in the design. Damaged parts will be relatively easy to replace.

Prefabricated units will be folded for easy shipment to the construction site. As a result of this standardization and prefabrication, the units are designed to be assembled, erected and disassembled in a minimum of time without skilled construction help.

Two-story balconies will be reached by four stairways. Intercommunciation between the upper floors of the balconies will be made possible by catwalks the full length of the hangar.

Airplanes will enter the hangar through 40-foot high openings. Doors are designed so that they may be stacked in the center of one side, thus permitting the hangar to be open on all sides.

Floor space in the original unit will be 80,000 square feet. Features of the design are said to make it adaptable to smaller or multistory buildings.

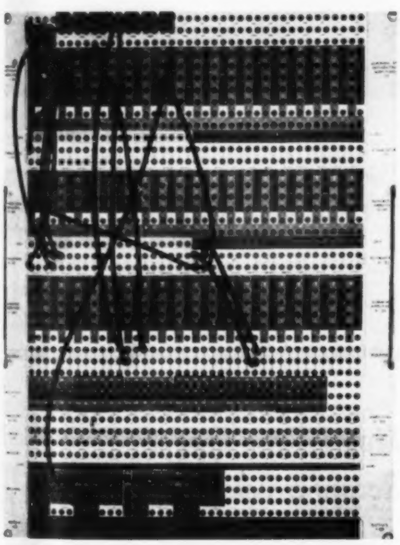
• • • WATERPROOF PAPER *which retains* 90 *per cent of its tensile strength after being soaked in water has been developed by the Shoe Products Div., Dewey and Almy Chemical Co. Ten times the abrasion resistance of paper impregnated by ordinary methods is claimed. The new method uses synthetic elastomers and resins and can be applied to various thicknesses of paper. Samples can be obtained from the manufacturer. Evidently those of us who buy cheap shoes need no longer worry about walking in the rain.*

Standard designation list covering the most popular grades of nickel-chromium alloys used for heat and corrosion-resistant castings has just been revised and published by the Alloy Casting Institute. Incorporating designation changes and several additional alloys, the revised chart of

chemical composition ranges is available from ACI headquarters, 32 Third Ave., Mineola, N. Y.

Have a Problem? Rent a Computer

Equipped to solve complex problems in engineering research and design, a new analog computer center has been opened near Princeton, New Jersey. Established by Electronic Associates Inc., the center has a staff of technical specialists for problem analysis and will provide equipment which may be rented on an hourly, weekly or monthly basis. Members of industry may have problems solved in

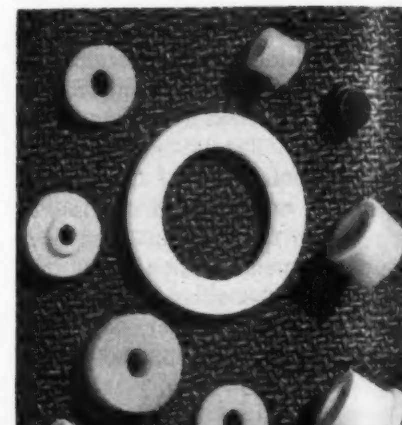


Removable analog computer patch panel may be set up in advance without tieing up operation of the computer

management operations control, dynamic systems analysis, applications engineering and simulation.

In announcing the establishment of the center, Lloyd F. Christianson, president of Electronic Associates Inc., said, "We feel that there is a growing need in industry for a facility such as we have established. It will prove particularly beneficial to the smaller companies which have not yet found it feasible to invest in their own computation facilities." To each problem, the center assigns the necessary scientists, engineers or math-

ematicians experienced in the use and applications of analog computers to evaluate, set up and solve problems submitted.



MOLDED ADHESIVES are now available to save assembly time. Made by Mansol Ceramics, the shaped resin is slipped on the parts to be joined and placed in an oven for curing

Metal Show Expects Record-Breaking Attendance

Exhibitors at this year's National Metals Exposition, November 1-5, expect an attendance of over 50,000 representatives of the nation's metalworking industry. A total of 442 exhibitors will have displays in over 6 acres of space in Chicago's International Amphitheatre. Featured will be the development and use of significant new metals, alloys, processes and production techniques.

Besides the American Society for Metals, three other participating groups will hold technical sessions. These are the American Welding Society, the Institute of Metals Div. of the American Institute of Mining and Metallurgical Engineers and the Society for Non-Destructive Testing. ASM has scheduled 39 technical papers

on a wide range of subjects. Show officials say that the sessions are timed to permit visitors to attend both the technical sessions and the exposition.

Two awards recognizing achievement in the metals field will be presented by the American Society for Metals. As a feature of the annual banquet, the ASM Research Medal and the Albert Sauveur Achievement Award will be presented.

Candidate for the ASM Medal is William E. Umstattd, president of Timken Roller Bearing Co. Alexander L. Feild, associate director, research div., Armco Steel Corp., is to be the Sauveur medalist.

ASM Medal for Advancement of Research is presented to an executive of an industrial organization engaged primarily in the production or fabrication of metals. He shall further have substantially helped advance metallurgical research and development. Mr. Umstattd has, according to ASM, sponsored metallurgical research at Timken that resulted in many new products.

Alexander L. Feild, 1954 Sauveur Medal winner, is one of the country's authorities on stainless steel. This award will recognize his metallurgical achievements that have resulted in marked basic advances in that field.

Further information about the show may be obtained by writing W. H. Eisenman, managing director, 7301 Euclid Ave., Cleveland 3, Ohio.

• • • REAL COOL CARS *are being driven in the southwest plains by motorists who stop at gas stations equipped with portable three-ton air conditioners built by Chrysler Airtemp. While the gasoline is being pumped into the trunk, a hose inserted through one of the windows pumps the interior of the car full of cool dry air. Although no scientific data are available on results, reports indicate that the service is appreciated and motorists return to stations making it available.*

(*Continued on Page* 44)

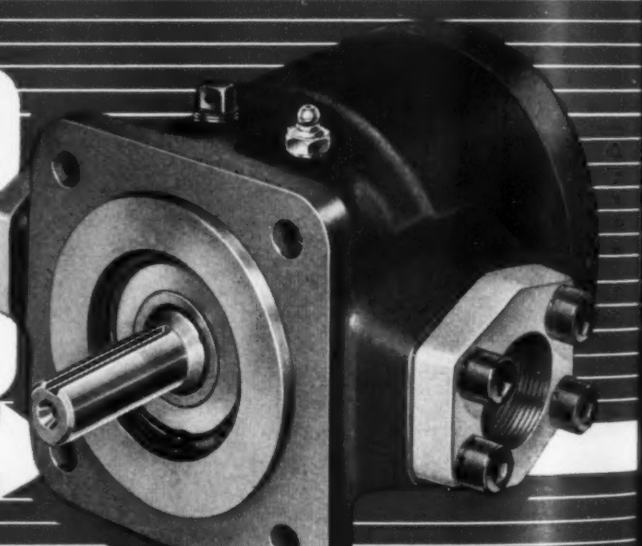
5000 PSI

FOUR COMPLETELY NEW LINES OF HYDRAULIC PUMPS WHICH GIVE YOU FAR MORE IN PERFORMANCE AT FAR LESS IN COST!

- Pumps to give new life to existing equipment . . . to improve performance, increase capacity!
- Pumps that afford the design engineer the basic equipment for entirely new concepts in hydraulically operated machines!
- Pumps for machines to do work better, quicker, cheaper!

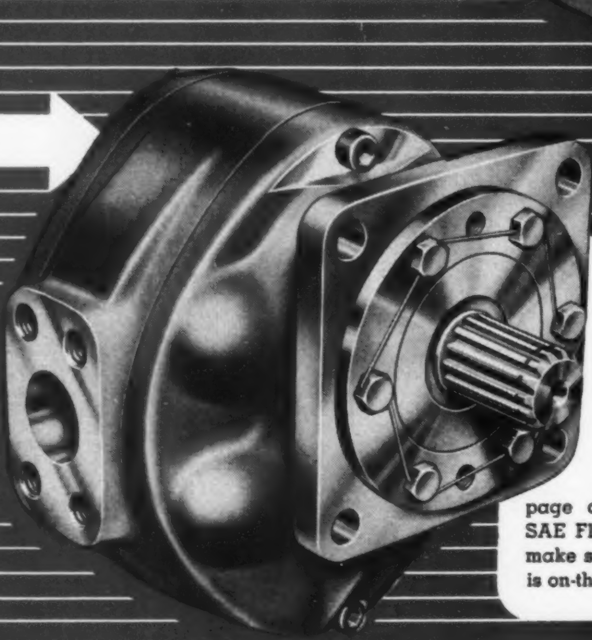
SERIES PF-100 VANE-TYPE PUMPS

DUDCO PF-100 Series Pumps can double the value of your *hydraulic dollar.* You get 2000 psi continuous duty, single-stage construction for the cost of equal capacity low pressure pumps . . . improved equipment design and increased machine efficiency without the payment of premium prices. These Pumps feature a simplified, 3-unit construction . . . the pumping cartridge incorporates the famous DUAL-VANE design which provides and assures complete balance of all hydraulic pressure loads. These Pumps have capacities of 3, 5, 8 and 11 gpm at 1200 rpm.



2000 PSI

1500 PSI

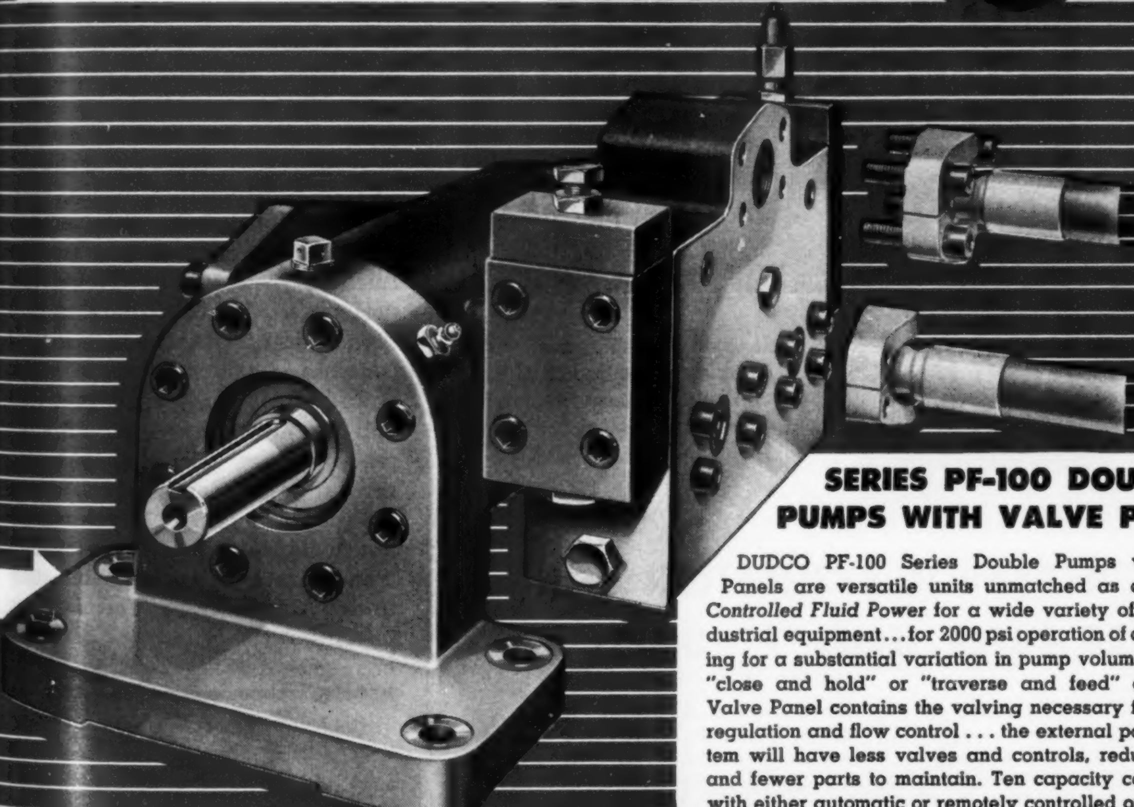


SERIES H GEAR-TYPE PUMPS

The HYDRECO Series H Pumps are intended for use in the hydraulic systems of heavy-duty mobile and industrial equipment, especially where shock loads, impact and rugged service are "normal working conditions". Four sizes (40, 50, 60, 70 gpm) deliver fluid power at 1500 psi . . . increased horsepower gives greater work output. *Pressure-Balanced* wear plates reduce oil slippage and eliminate power-robbing frictional contacts. SAE Flange Mounting and split-flange hose connections make servicing simple and reduce down-time. Equipment is on-the-job longer.

SERIES PV-600 PISTON-TYPE PUMPS

DUDCO PV-600 Series Variable Delivery Pumps generate continuous duty pressures up to 5000 psi. Two types of controls match pump output to system demands. A pressure-compensated regulator automatically varies the volume in response to system pressure. A hand wheel control enables an operator to vary the volume during the machine cycle. High pressure variable delivery means power is transmitted without the necessity for an accumulator and without any wastage of power thru a relief valve.



SERIES PF-100 DOUBLE PUMPS WITH VALVE PANELS

DUDCO PF-100 Series Double Pumps with Valve Panels are versatile units unmatched as a source of *Controlled Fluid Power* for a wide variety of modern industrial equipment...for 2000 psi operation of circuits calling for a substantial variation in pump volume as during "close and hold" or "traverse and feed" cycles. The Valve Panel contains the valving necessary for pressure regulation and flow control . . . the external part of a system will have less valves and controls, reduced piping and fewer parts to maintain. Ten capacity combinations with either automatic or remotely controlled operation.

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☐ SERIES H GEAR-TYPE PUMPS

☐ SERIES PF-100 DOUBLE PUMPS WITH VALUE PANELS

☐ SERIES PV-600 PISTON-TYPE PUMPS

Name____________________

Address____________________

City________ Zone____ State______

News Roundup

(*Continued from Page* 41)

Atomic Engineers?

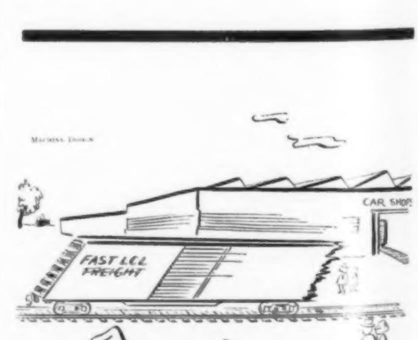
Nuclear engineering is to be taught graduate engineers in a course offered by Illinois Institute of Technology. Because of recent technical advances in this field, many engineers find they need supplementary education to keep pace, the school reports. Industry's demand for engineers with sufficient knowledge of nucleonics prompted the initiation of the new course.

Elementary particles and radioactivity will be studied and typical nuclear reactions and their kinetics, including decay constants and half lives, will be covered by the course.

The course will include development of reactor theory and the history of neutrons in a nuclear reactor. Also included will be calculation of neutron flux and the diffusion of neutrons by Fick's law, derivation of "pile" equations, and discussion of reaction kinetics and control.

Radiation damage to materials and chemical processing of spent reactor cores also are to be described in the course.

Prerequisites for the nuclear engineering course are a bachelor's degree from an accredited institution in engineering, chemistry or physics.



"We've built the illusion of speed right in."

Sour Notes Rule Out Bad Steel

One of the machines now being used for endurance limit research of steel at U. S. Steel's Research and Development Laboratory in Pittsburgh is a magnetic fatigue tester. Samples of steel from 24 to 36 inches in length and up to 2 inches thick and 5 inches wide can be subjected to controlled vibrations at the natural frequency of the test piece.

A piece of steel is placed on rubber-padded supports and magnets are positioned under the end of the sample. An alternating current is then supplied to the end magnets to set the steel vibrating, much after the fashion of a tuning fork.

Each test piece has a natural frequency at which it will vibrate, the natural frequency depending on the dimensions of the piece. Pickup coils at the center of the sample translate the motion into electrical impulses which feed back to a power unit at the natural frequency of the sample. These impulses control the pulsations of electricity from the power unit to magnets at each end of the sample so they match the frequency of the specimen and keep it vibrating. Amplitude of the sample's vibrations depends on the intensity of the current supplied to the end magnets.

When a crack develops in the test specimen, its natural vibrational frequency changes. This change upsets the rhythm of impulses from the pick-up coils to the power unit and the machine automatically stops.

By use of a microcomparator, the research scientist can easily measure the amplitude of the vibration or the amount of bending.

A stroboscopic light is used to establish the location of very small fatigue cracks. This is done by adjusting the light from the stroboscope to a frequency slightly higher or slightly lower than that of the vibrating sample. In this light, the test piece appears to be bending very slowly and its sur-

faces can be carefully examined for very small cracks.

A test sample about ¾-inch thick by 3 inches wide by 30 inches long will vibrate at about 100 cycles per second. Middle C in the diatonic scale is 256 cycles per second and C below middle C is 130 cycles per second or almost 8000 per minute. Past experience and innumerable tests have proven that if a specimen can endure 10 million cycles at a certain amplitude without failure, it will withstand an infinite number of vibrations at that amplitude.

If a structural component is desired with a minimum of 20,000 psi endurance limit, the research scientist can very quickly determine on the magnetic fatigue tester the steels that will meet the requirement.

Endurance Tests Promise More Powerful Gas Turbines

Successful completion of tests of an experimental gas turbine with critical parts made of sintered titanium carbide has been announced by Kennametal Inc. Test runs of up to 100 hours continuous operation were reported at impeller temperatures of up to 1900 F. Previously, the best time achieved at that temperature was said to be 4 minutes. Impeller speed was 30,000 rpm.

Use of the metal, called Kentanium, is expected to increase the efficiency of gas turbines by increasing operating temperatures. Power and efficiency of gas turbines is affected by operating temperatures. An increase from the present normal operating temperature of about 1400-1600 F to 1900 F is said to increase power output 50 per cent. An efficient turbine using a 7-inch diameter impeller running at the maximum allowable temperature should deliver 125 horsepower.

Kentanium is composed of 54 per cent titanium carbide, 40 per cent nickel and the remaining 6 per cent columbium-tantalum carbide. Since it contains no tungsten, it is expected to be relatively cheap

when produced in greater quantities.

Production of the new metal is by powder metallurgy techniques. As part of the process, the metal

Impeller assembly of Kennametal's experimental gas turbine. Sintered titanium-carbide impeller is shown attached to the turbine shaft

powder is placed in a rubber bag which is inserted into the breech of a gun along with a powder charge. Pressure exerted as a result of firing the charge causes a 50 per cent reduction in volume. The metal cake is subsequently machined into the desired part.

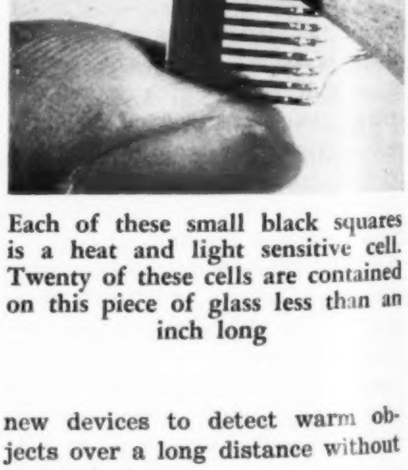
Further development of sintered titanium carbide is expected to increase the turbine operating temperature range up to 2300 F. Kennametal engineers say this will approximately triple power output. Fuel efficiency may also be improved.

New Trade Name for Elwell-Parker Electric Company's line of industrial trucks is "Elpar." This change has been made, according to company officials, to make it easier to identify the company's products. No change has been made in the company's management, ownership or policies.

Super-Sensitive Detector Will Locate Warm Objects

Glass coated with lead sulfide can give 10,000 times as much sensitivity to certain infrared rays as previous laboratory instruments, according to Eastman Kodak engineers.

Known as Kodak Ektron Detectors, the new photoconductive cells have recently been made available to science and industry. It is expected that the extreme infrared sensitivity of the cells will open new possibilities to designers and engineers. Their simplicity and reported ability to be made in any size and shape will make possible new devices to detect warm objects over a long distance without physical contact.



Each of these small black squares is a heat and light sensitive cell. Twenty of these cells are contained on this piece of glass less than an inch long

In addition to their possibilities for heat detection and for replacement of present types of photocells in rough service applications, these detectors are expected to have applications in automatic control of chemical processing plant operations and in complex electrical equipment where mechanical switching devices are too bulky, impractical, or insufficiently reliable.

In the chemical plant applications, the cells could automatically monitor the exact composition of fluids flowing through pipes and process vessels on the basis of the characteristic infrared "color" of the various components. Water and gasoline, for example, are both colorless liquids to the human eye but look entirely different to a sensitive infrared detector. Very fine differences between chemicals can be detected in this way.

In the switch applications, say the Kodak engineers, the Ektron Detector permits a beam of light to eliminate a moving part. The "light", they point out, can come from a lamp operated so far below the rated current that the glow is invisible.

Though the cell is most sensitive to near-infrared rays, it is said to be highly sensitive to all colors of visible light up to and including ultraviolet.

Standards Engineers To Discuss Color TV

Color television, safety, international standards, purchasing and quality control are subjects to be

POWERFUL SHAKER delivers up to 12,500 pounds force. Produced by MB Mfg. Co. Inc., this vibration exciter is said to be the largest capacity electromagnetic shaker in existence. Operating range is from 5 to 2000 cps. Built-in vibration isolators eliminate the need for special floor construction

featured at the forthcoming Fifth National Conference on Standards. To be held in New York on November 15, 16 and 17, 1954, the conference will also include the thirty-sixth annual meeting of the American Standards Association.

Roger E. Gay, president of Bristol Brass Corp. and president of the American Standards Association will give the keynote address. The Howard Coonley Medal and the Standards Medal will be presented at the annual award luncheon during the session.

Meetings

AND EXPOSITIONS

Oct. 11-12—

Second Conference on Mechanisms. Two-day conference to be held at Purdue University, West Lafayette, Ind., under the joint sponsorship of the editors of MACHINE DESIGN and *Automation*, and the faculty of the school of mechanical engineering at Purdue University. Additional information may be obtained from the Editor, MACHINE DESIGN, Penton Bldg., Cleveland 13, O.

Oct. 11-15—

American Institute of Electrical Engineers. Fall general meeting to be held at the Morrison Hotel, Chicago, Ill. H. H. Henline, 33 West 39th St., New York 18, N. Y., is secretary.

Oct. 24-27—

American Gear Manufacturers Association. Fall meeting to be held at the Edgewater Beach Hotel, Chicago, Ill. John C. Sears, One Thomas Circle, Washington 5, D. C., is executive secretary.

Nov. 1-5—

American Society for Metals. Thirty-sixth national metal congress and exposition to be held in the International Amphitheatre, Chicago, Ill. W. H. Eisenman, 7301 Euclid Ave., Cleveland 3, O., is managing director.

Nov. 1-5—

National Metal Congress & Exposition to be held at the International Amphitheatre, Chicago, Ill. W. H. Eisenman, 7301 Euclid Ave., Cleveland 3, O., is managing director.

Nov. 1-5—

American Welding Society. National fall meeting to be held at the Sherman Hotel, Chicago, Ill. Additional information may be obtained from society headquarters, 33 West 39th St., New York 18, N. Y.

Nov. 11-12—

Gray Iron Founders' Society Inc. Annual meeting to be held at The Homestead, Hot Springs, Va. Additional information may be obtained from society headquarters, National City-East 6th Bldg., Cleveland, O.

Nov. 28-Dec. 3—

American Society of Mechanical Engineers. Annual meeting to be held at the Statler Hotel, New York, N. Y. C. E. Davies, 29 West 39th St., New York, N. Y., is secretary.

Dec. 5-9—

Scientific Apparatus Makers Association. Fall meeting to be held at the Pinehurst Hotel, Pinehurst, N. C. Additional information may be obtained from society headquarters, 20 N. Wacker Dr., Chicago, Ill.

Dec. 5-8—

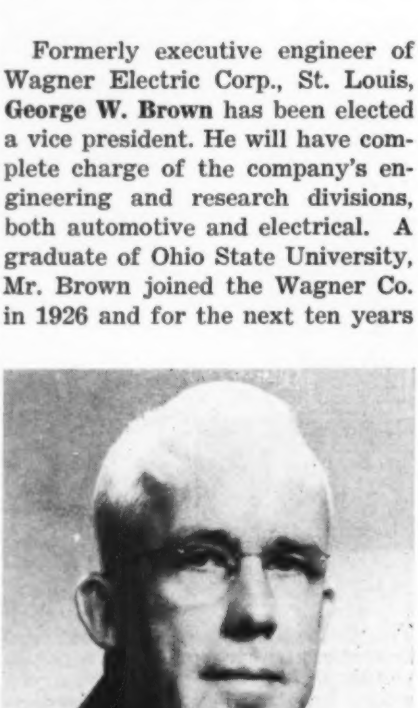
American Society of Agricultural Engineers. Winter meeting to be held at the Edgewater Beach Hotel, Chicago, Ill. Additional information may be obtained from society headquarters, P. O. Box 229, St. Joseph, Mich.

Dec. 12-15—

American Institute of Chemical Engineers. Annual meeting to be held at Hotel New Yorker, New York, N. Y. Additional information may be obtained from society headquarters, 120 E. 41st St., New York 17, N. Y.

MEN
OF MACHINES

Formerly executive engineer of Wagner Electric Corp., St. Louis, **George W. Brown** has been elected a vice president. He will have complete charge of the company's engineering and research divisions, both automotive and electrical. A graduate of Ohio State University, Mr. Brown joined the Wagner Co. in 1926 and for the next ten years



George W. Brown

was associated with the electrical engineering department, specializing in the development, design and application of fractional-horsepower motors. In 1952, after serving in other capacities in the firm and with the U. S. Army Ordnance Department, he was made executive engineer. Mr. Brown is a member of the Society of Automotive Engineers, the American Institute of Electrical Engineers, the Association of Iron and Steel Engineers, the American Ordnance Association and the Engineers' Club of St. Louis.

Massachusetts Institute of Technology, Cambridge, Mass., has appointed **Dr. Jacob P. Den Hartog** head of the Department of Mechanical Engineering. Since 1945 he has been in charge of the division of applied mechanics of this department. An authority in the field of mechanical vibrations, Dr. Den Hartog was associated with the Research Laboratory of Westinghouse Electric Corp. in Pittsburgh, specializing in problems in dynamics and mechanical vibrations. He was subsequently a member of the faculty of Harvard University, and during World War II he served with the U. S Navy.

Newly appointed head of the engineering department of Norton Co., Worcester, Mass., **Herbert A. Silven** succeeds **Carl G. Flygare**, who retired after 47 years with the company. Mr. Silven, who did much of the original work on Norton's first automatic cam and crank grinding machines, has been directly responsible for 60 patents.

Fellows Gear Shaper Co., Springfield, Vt., has announced that **Bernard L. Ward**, formerly chief of machine design, has been appointed assistant chief engineer. He retains responsibility for machine design, with **Harry King** as his assistant in that department. Concurrently, the company appointed **Henry G. Stone** chief of tool design, with **Carl H. Parker** as assistant, and **J. L. Williamson** chief of research, with **Roland Seavey** as assistant.

Appointment of **Nicholas N. Solovioff** to the operational staff, as head of the newly formed Production Engineering department, has been announced by Greer Hydraulics Inc., Jamaica, N. Y. Reporting directly to the president and

(Continued on Page 57)

(Continued from Page 52)
chief engineer, Mr. Solovioff will act as liaison between the engineering and manufacturing departments. Pilot, designer, inventor and manufacturer, he has been connected with the aviation industry for more than 30 years.

Prof. Harold A. Bolz has assumed duties as associate dean of the College of Engineering of Ohio State University, Columbus, O. A member of the Purdue University faculty since 1938, Prof. Bolz served successively as assistant professor of machine design, associate professor of mechanical engineering, professor of industrial engineering and head of the general engineering department. Prior to joining the staff at Purdue, he was a development engineer for the Weatherhead Co. in Cleveland. He received B.S. and M.S. degrees in mechanical engineering from Case Institute of Technology.

In recent years, Prof. Bolz has supervised the planning and organization of campus conferences for industry in seven different engineering fields, and he is at present a consultant to several companies on technical conferences. Active in the American Society of Mechanical Engineers, he served as chairman of the Central Indiana Section in 1950. He is a member of the American Society for Engineering Education and was editor of Machine Design Clearing House Bulletin in 1944-1946. He is also a member of the Indiana Engineering Council, is a registered professional engineer and holds memberships in the Society for the Advancement of Management, American Association for the Advancement of Science and the Indiana Personnel Association. Prof. Bolz is the author of numerous papers and articles, several of which have been published in MACHINE DESIGN.

Harold A. Bolz

Edward H. Heath has been appointed manager of quality control at Howell Electric Motors Co., Howell, Mich. Mr. Heath was formerly chief engineer at Marathon Electric Corp., Erie, Pa., and prior to that served as design engineer with several other companies.

W. C. Jenner has joined Houghton Laboratories Inc., Olean, N. Y. as chief electrical engineer. He formerly was a member of the engineering department of Reliance Electric and Engineering Co., Cleveland.

Ford Motor Co., Dearborn, Mich., has named **V. Y. Tallberg** director of engineering administration and executive assistant to the vice president in charge of engineering.

B. F. McNamee has been appointed chief of research and development of motor controls and power supplies for Dressen-Barnes Corp., Pasadena, Calif. **Alvin L. White**, layout and design engineer, recently returned to the firm from active duty with the U. S. Army Signal Corps.

Goodyear Aircraft Corp., Akron, O., recently announced the appointments of **Albert W. Cook** as chief project engineer, **Donald G. Smellie** as head of the research and development section and **Charles F. Luginbill** as head of all testing activities and laboratory operations within the aircraft wheel and brake development department. Having joined the Goodyear Tire & Rubber Co. in 1938, Mr. Cook was transferred to the company's

Men of Machines

engineering squadron at Akron in 1939. Mr. Smellie was associated for 29 years with the Hoover Co. of North Canton, O., ultimately as director of the engineering division, and then was chief engineer of Industrial Service Co. of North Canton until joining Goodyear Aircraft in April 1954. Mr. Luginbill has been associated with wheel and brake development operations at the company since 1943.

Charles J. Parker has been named electrical engineer to head the electrical research division of

Charles J. Parker

Studebaker Corp., South Bend, Ind. He succeeds **T. E. Wagar,** who has retired. A graduate of Tri-State College with a B.S. degree in electrical engineering, Mr. Parker has been a member of the Studebaker engineering staff for 29 years.

Lombard Corp., Youngstown, has promoted **A. P. Sgambati** to the position of chief engineer.

Recent changes at the Norwood, O., works of Allis-Chalmers Mfg. Co. include the appointment of **Thomas C. Knudsen,** former manager of the Texrope Drive Section, to the post of assistant to the general manager in charge of the mechanical product development laboratory. Concurrently, the company

named **Vernon B. Honsinger,** former engineer-in-charge of the research laboratory, as assistant to the general manager in charge of the electrical product development laboratory.

J. L. DeDiemar

J. L. DeDiemar, former Convair design specialist, has been appointed chief engineer of Resdel Engineering Corp., Los Angeles. Mr. DeDiemar joined Convair's engineering department in 1936 and the following year was transferred to the San Diego division, where he has been an electronics project engineer. He also served as staff assistant in the electronics section for several years. He was formerly an electronics engineer with Gilfillan Bros. Inc., Los Angeles. Mr. DeDiemar received a B.S. degree in electrical engineering from Iowa State College in 1943.

George S. Trimble Jr. recently was elected vice president in charge of the newly created advanced design division of Martin Aircraft Co., Baltimore.

Announced recently were the appointments of **Raymond S. Fox** to chief engineering consultant of the gage division and **Charles A. Whitney** to chief engineer of the gage engineering department of Pratt & Whitney Div., Niles-Bement-Pond Co., West Hartford, Conn.

J&H Motors on 24-hour duty in

HERE WAS THE NEED

Given Manufacturing Company of Los Angeles needed a rugged, specially built motor to power its famous WASTE KING Commercial *Pulverator* . . . a heavy-duty garbage disposer designed for commercial and institutional use. Installed in a kitchen's critical food-waste "point-of-origin", the unit had to have a motor that would operate on a 24-hour basis under variable peak loads, high heat and moisture.

Customized JACK & HEINTZ

MACHINE DESIGN
OCTOBER 1954

The Disorganized Profession

SUCCESSFUL engineers must be good organizers. Facts must be organized for engineering decision; equipment must be organized for production; people must be organized to carry a job through. Why then are engineers so backward in organizing their own profession for action?

Doctors have their medical associations and lawyers their bar associations. These organizations effectively care for all the professional needs of their members. By contrast, engineers seem to need at least two professional organizations—the engineering societies like ASME, and the NSPE group composed of registered engineers.

But neither group has taken sufficiently vigorous action—either separately or jointly—on the welfare and economic status of engineers employed in industry. As a result, a third group has risen—the collective bargaining agencies such as the Engineers and Scientists of America.

The ESA claims to have been the sole contender on behalf of the engineering employee in protesting a recent wage-hour ruling on overtime payment to professional-exempt employees. While the group succeeded in obtaining an important modification, features still in the regulations permit employers to take unfair advantage of professional-exempt employees. The professional societies could have added the weight of their influence to promote more effective action and greatly enhanced their own status in the eyes of an increasingly critical younger generation of engineers.

Our engineering and professional societies include people at all levels of activity from top management down to beginners just out of college. Perhaps those in control feel that specific action on behalf of the engineering masses is beyond the province of a professional society. But by leaving those in the lower ranks to organize themselves for collective action, the leaders of the profession are, in effect, encouraging disunity rather than the unity to which they give such eloquent lip service.

Colin Carmichael
EDITOR

Selection and

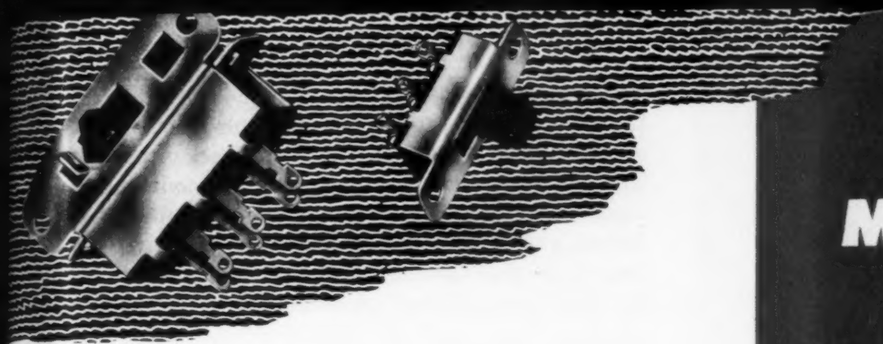
By Keith A. Carlson

Assistant Editor, Machine Design

INCREASING complexity of production machines, the advent of more and more electrical home appliances and increasing use of electrically operated controls have all contributed to increasing concern of the designer with the selection and application of multiple-circuit switches. Although a number of single-circuit switches could, in many but not all instances, be used in place of a multiple-circuit switch, there are many economic, engineering and human factors which dictate the use of the multiple-circuit switch when possible.

From the standpoint of economy, multiple-circuit switches have multiple advantages. First is cost; a multiple-circuit switch will almost invariably cost less than the number of single-circuit switches required to perform the same switching operations. Other cost advantages are almost obvious and result from the economy inherent in the replacement of many items by a single item. Fewer holes have to be drilled for mountings; fewer connections must be made in assembly since many of the connections are integral with the switch assembly; and presumably some saving might be realized through reduction in the length of wire used for making connections. Superior designs of smaller size and lighter weight are an almost inevitable result of the use of multiple circuit switches.

Human factors dictate the use of multiple-circuit switches in many instances. An automobile light switch could be replaced by three separate switches—one for headlights, one for tail lights, and one for parking lights. But what of the added inconvenience to the driver and the possibility of forgetting to turn *on* or *off* certain lights? These



MULTIPLE—CIRCUIT SWITCHES

Application of Lever-Operated Switches

same observations hold true for many other machines; however, the magnitude of complexity could be much greater and the result of an operator's error could be disastrous.

Switch Types: Both manual and powered operation of switches are possible. Since driven switches are usually adaptations of existing manually-operated types, only manual switches will be considered in this series of articles. Motion required of the operator serves as a convenient method of dividing switches into three primary groups: (1) lever, (2) rotary and (3) push or pull-operated switches. Physical and electrical characteristics of lever-operated types will be considered in this article. Future articles will cover these features of the remaining groups and the specific factors influencing selection.

Lever-operated Switches: Fundamental types of lever-operated switches are:

1. Toggle switches
2. Snap-action push switches with toggle actuators
3. Lever-actuated leaf spring buildups
4. Lever-actuated rotary switches
5. Slide switches
6. Mercury switches

All lever-operated switches have certain common characteristics. One of the most important of these is visual indication by lever position of

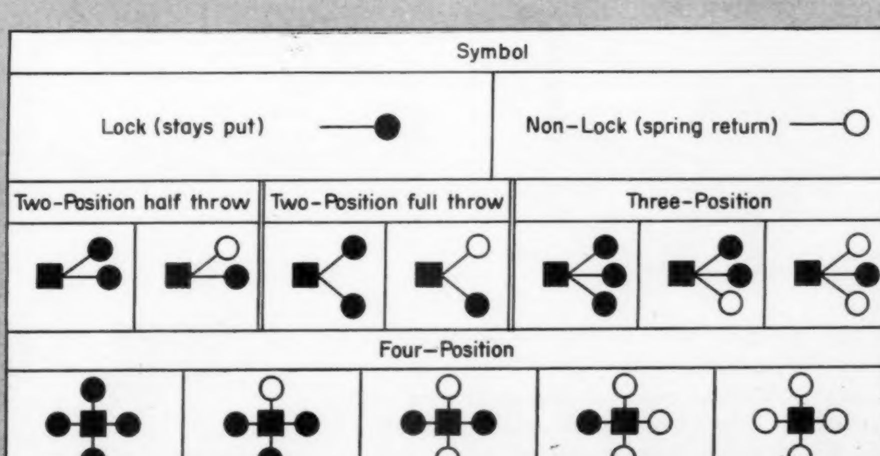


Fig. 1—Possible actuating lever movements for toggle, toggle-actuated snap-action, and lever-actuated leaf-spring buildup switches. Four-position switch is leaf-spring type

whether the switch is *on, off,* or otherwise, *Fig.* 1. Five lever positions are possible with a lever-operated switch. Other characteristics are: small size, *Fig.* 2, light weight, simple mounting arrangements and relatively low cost. Number of different switching arrangements possible with one switch is not usually as great as for certain of the rotary or pushbutton switches.

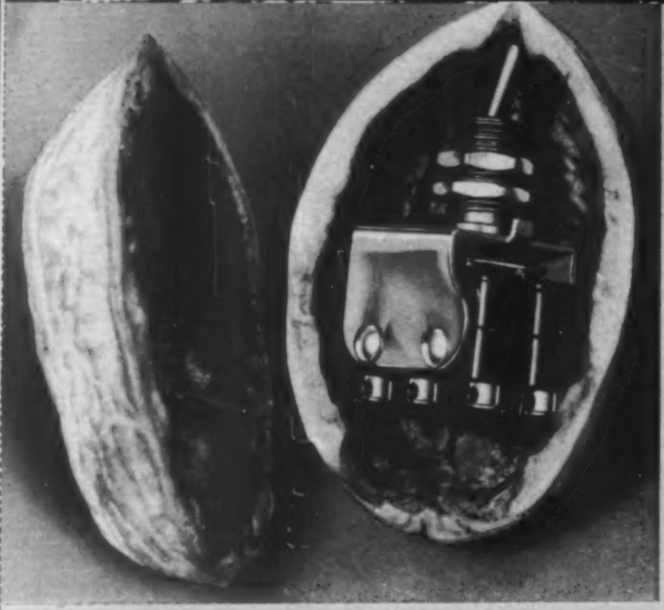


Fig. 2—Above—Small size possible with lever-actuated switches is shown by this double-pole, double-throw switch in a walnut shell. Consisting of two small snap-action push switches with toggle actuator, the switch weighs approximately ½-ounce. Ratings are 2 amperes at 30 volts dc for resistive or inductive loads and 5 amperes at 125 or 250 volts, ac

Toggle Switches: Contact arrangement of toggle-switches is usually limited to four-pole, double-throw, *Fig.* 3, with three possible positions of the toggle lever. Conventionally, with toggle lever throw to either end position one circuit is connected while the other circuit is disconnected, either with or without a center "off" position where neither circuit is connected. A variation of this arrangement is the progressive two-circuit switch which disconnects when the toggle lever is at one end position, connects one circuit with the toggle lever centered and connects both circuits with the toggle lever at the other end position. Standard types are available which maintain contact at one or both of the end positions only so long as the lever is held, and the lever automatically returns to the center position when released, *Fig.* 1.

Because of the toggle operating mechanism, make or break time of the contacts is independent of force applied by the operator; contacts always open or close with a snap. This fast action, particularly when points are opening, prevents arcing thereby increasing contact point and switch life. Current and voltage ratings for a typical switch are given in *Table* 1.

Mounting arrangements are of two types; (1) single-hole or bushing mounting in which the bushing around the toggle lever is threaded and

Fig. 3—Below—Typical four-pole, double-throw toggle switch. This unit has a sealed toggle lever to prevent entry of moisture or foreign matter. Mounting is three-hole type. Electrical ratings are 12 amp at 30 v dc and 15 amp at 115 volts ac for inductive loads. Dimensions are 2⅛ inches long, 1 33/64 inch wide and 1 21/64 inch high. Toggle lever is ⅞-inch long, and weight of the complete switch is 3 ounces or less

Table 1—Electrical Characteristics of Typical Toggle Switch

Load Type	Voltage, ac (v)	Voltage, dc (v)	Current (amp)
Resistive	...	30	30
Resistive	...	125	0.75
Resistive	...	250	0.50
Resistive	115	...	25
Resistive	230	...	9
Lamp	...	30	7
Lamp	125	...	4
Inductive	...	30	15
Inductive	125	...	8

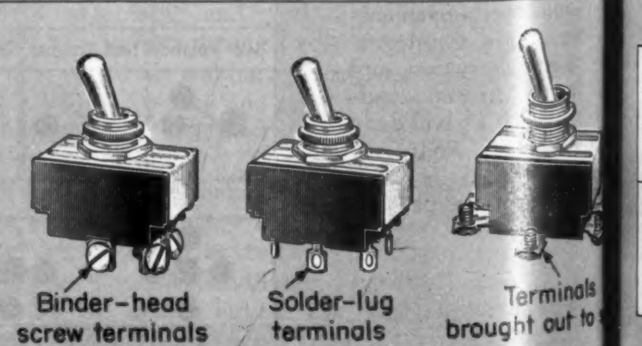


Fig. 4—Right—Various types of terminals used on toggle switches. Terminals brought out at side may be either binder-screw type shown or solder lugs. These switches are for single-hole mounting

the switch is held to a panel by locknuts on each side of the panel and (2) three-hole mounting, *Fig.* 3, in which two screws go through the panel into nuts on a mounting plate attached to the switch. Wire terminals may be solder-lug, binder-head screw or wire lead type and may be brought out at ends and sides of the switch, or on the bottom, *Fig.* 4. Plates bearing markings to indicate whether the switch is "off" or "on" are available as standard items.

Lever-Actuated Push Switches: Snap-action push switches fitted with toggle lever actuators are available. Although lever positions are limited to five, the number of switches which can be actuated by one lever and the possibility of combining switches having normally open and normally closed contacts in one assembly can produce extremely versatile arrangements, *Fig.* 5.

Basic switch units used are small, push-operated

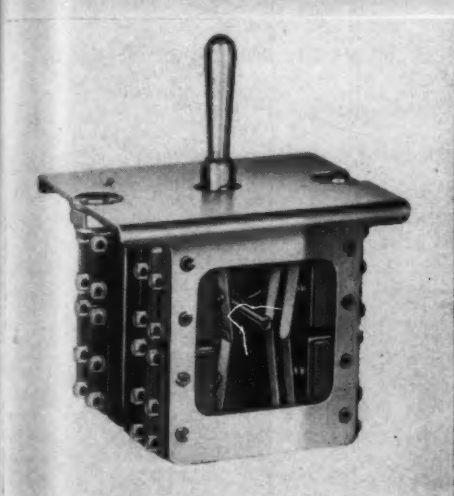
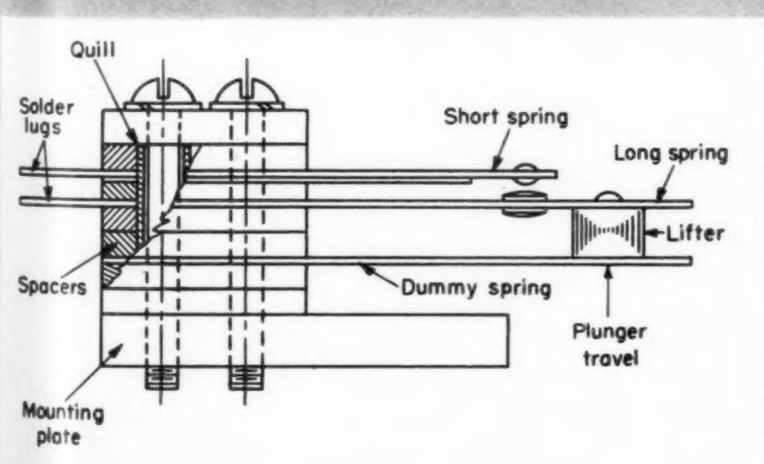


Fig. 5 — Left — Assembly of 16 subminiature snap-action switches with double throw arrangement on each switch. Operation of all switches on either throw may be either simultaneous or in predetermined sequence. Units have been built with five positions of the actuating lever, each producing a different combination. This assembly is only 2⅛ inch long, 1 15/16 inch wide and 1 21/32 inch high, excluding the toggle lever

Fig. 6—Below—One of the eight basic types of leaf - spring buildups. Form A or normally open contacts are shown

Fig. 7—Above—Four individual circuits can be controlled by this switch assembly. Building blocks are leaf-spring buildups. Single-hole mounting arrangement is used



Form A	Form B	Form C	Form D
Normally open	Normally closed	One side normally closed (SPDT)	Make before break
Form E	Form F	Form G	Form H
Break—make before break	Both sides normally open (SPDT)	Both sides normally closed (SPDT)	Make—make

Fig. 8—Left — Common leaf spring buildups shown may be used in various combinations to make up multiple-circuit switches

types with single-pole, double-throw arrangements. Details of the basic switches including voltage and current-ratings will be discussed in a later installment.

Mounting arrangements and terminals are usually the same as for toggle switches. That is, single or three-hole mountings and solder-lug or binder-screw terminals. Wire leads are also available on at least one adaption of a push type switch to toggle lever operation. Toggle lever action may be either momentary or detented.

Lever-Actuated Leaf Spring Buildups: Leaf spring buildups, *Fig.* 6, often called key switches, are available in various combinations with lever actuators, *Fig.* 7. Multiples of the common buildups, *Fig.* 8, are used to obtain required switching setups. A mechanical limitation to the number of

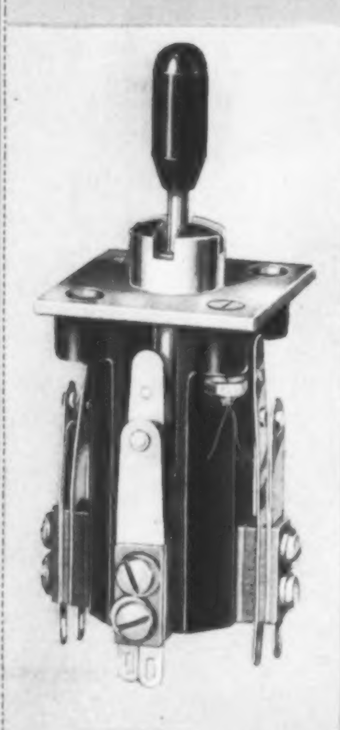


Fig. 9—Lever of this switch may be moved left, right, forward or backward in addition to a neutral or centered position. Mounting arrangement is three-hole type

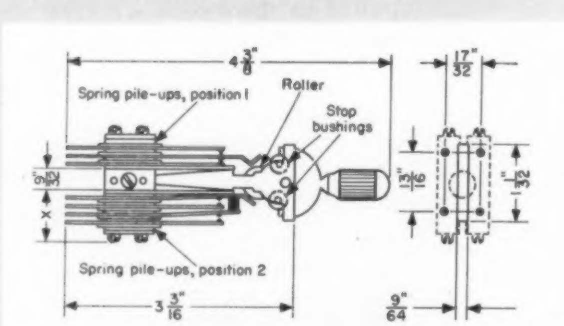


Fig. 10—Dimensions of a typical key switch. Dimension *X* varies with complexity of the pile-up

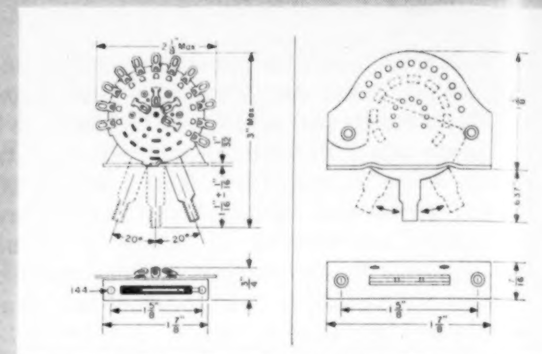


Fig. 11—Rotary switches are small in size and offer quite versatile switching arrangement. Two typical switches are shown

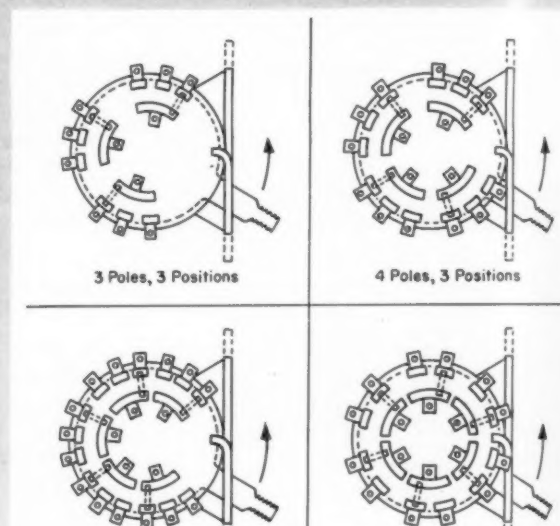


Fig. 12 — Typical contact arrangements available with lever-operated rotary switches

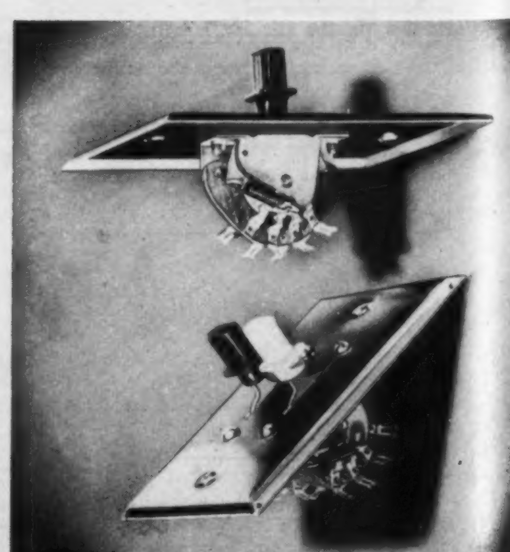


Fig. 13 — Plates are available for mounting as many as five rotary lever switches, side-by-side

buildups which may be used in each lever position is imposed by spring pressure. Two buildups of 12 springs each, or 24 springs, can usually be considered the practical maximum.

Lever positions are usually the same as for toggle switches, although four-way lever actuated leaf spring switches are made, ***Fig.*** **9.** Mountings for these switches may be single, three or four-hole type. Length of key switches in back of the mounting panel tends to be somewhat greater than for previously discussed types, because of the construction used, ***Fig.*** **10.**

For applications where switches may be subjected to extreme vibration or shock, or where it is necessary to guard against accidental operation of the switch, key switches may be provided with a lever locking device. A small button at the end of the lever handle must be depressed before a switch fitted with the lock can be operated.

Leaf blades of the basic buildup may be made of phosphor bronze, beryllium copper, nickel, silver or other alloy which will provide the necessary strength, corrosion resistance and resistance to repeated deflection. Blades are insulated from each other and from the mounting plate by spacers and insulating tubing around the clamping screws.

Contact points are made from various materials such as palladium, tungsten, platinum-ruthenium and silver alloys. Current carrying capacity varies with contact material, ***Table*** **2,** with 10 amperes at 115 volts ac being about maximum. These switches may be obtained with insulation to withstand voltages as high as 2000 volts dc and 1250 volts ac, rms.

Lever-Actuated Rotary Switches: As many as four positions of the operating lever and six poles are available with lever-actuated rotary switches. This variety of switching arrangements coupled with small size, ***Fig.*** **11,** results in a versatile switch in a small package.

In operation a rotor wipes contact segments on a stationary plate to complete the various circuits, ***Fig.*** **12.** Switches are supplied with detent or indexing action to maintain contact at a selected position, or with spring return to a neutral posi-

Table 2—Characteristics of Typical Key Switch Contact Points

Material	Diam (in.)	Height (in.)	Load-Carrying Capacity (amp)	(W)	Break or Make Load (amp)	(W)
Palladium-silver	0.067	0.020	3	150	3	135
Palladium	0.067	0.020	3	150	3	135
Platinum-ruthenium	0.067	0.020	3	150	3	150
Palladium	0.084	0.031	3	150	3	150
Platinum-ruthenium	0.084	0.031	3	150	3	150
Tungsten	0.188	0.062	6	650	4	450
Silver	0.250	0.062	10	1150	5	575

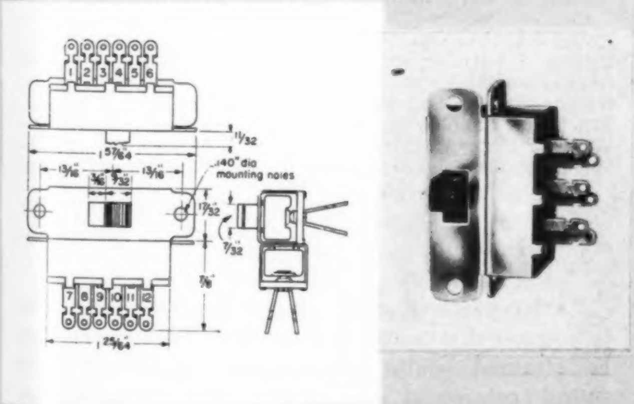


Fig. 14—Above — Four-pole, double-throw slide switch has terminals coming out both bottom and side to keep size down. This switch is rated 0.5-amp at 125 volts ac or dc

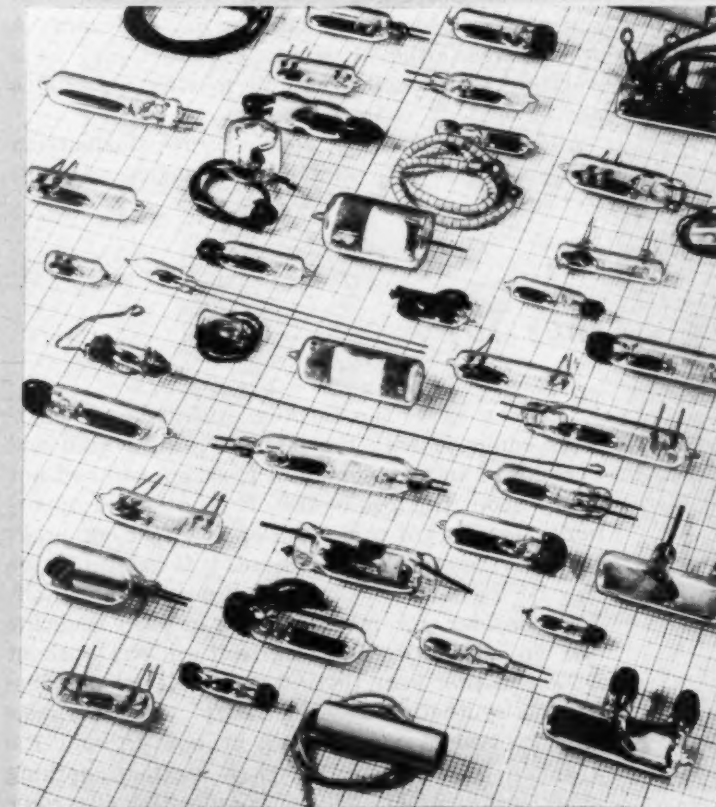


Fig. 15—Right—A variety of types and sizes of mercury switches are available. Some are encased in protective housings to decrease possibility of breakage

tion. Neutral position may be "off" or may maintain a circuit at the designer's discretion.

Some typical make or break current ratings for this type of switch are 1 ampere at 6 volts dc, 0.12-amp at 100 volts dc, 0.15-amp at 100 v ac, and 0.05-amp at 250 v dc. Insulation is usually of high-quality laminated phenolic material. Terminals and contacts are usually silver plated.

Mounting is three-hole type with the hole for the operating lever being a narrow slot. Mounting plates are available from at least one manufacturer which permit mounting of as many as five switches, side by side, *Fig* 13. Terminals are the solder-lug type.

Slide Switches: Small size and reasonably high current-carrying capacity characterize the slide type lever-operated switch, *Fig.* 14. Motion of the operating lever is linear. Limit of multiplicity of contacts is four pole, double throw.

Typical Underwriters' approved ratings are from 0.5 to 0.75 amp at 125 v ac or dc. Mounting arrangement is the three-hole type. Terminals are solder lugs.

Mercury Switches: A glass tube containing a pool of mercury, pure hydrogen and two or more electrodes, *Fig.* 15, which are connected by the pool of mercury when the tube is correctly tilted, make up a mercury switch.

Since there are no moving parts, except the mercury, there are no moving parts to wear. Because hydrogen, mercury, the glass tube and the electrodes are inert with respect to each other, switch characteristics do not change over long periods of operation. Sealed construction also makes mercury switches safe for use in hazardous atmospheres, although shock or impact may be a problem. Additionally, use on moving assemblies may be difficult or impossible.

Although double-pole, double-throw construction is the most complex switching arrangement available, the designer must usually work out his own tilting or actuating arrangement and while so doing can arrange to actuate more than one switch with same mechanism. Degrees of tilt to actuate the various types vary from 0.5 to 12; this allows increased versatility of multiple mercury switching set ups.

Electrical ratings for mercury switches vary from 1 to 25 amperes at 115 v ac for resistive loads. Terminal connections are usually made to extensions of the electrodes to the outside of the glass tubes, although flexible wire leads are also used.

ACKNOWLEDGEMENT

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Allen-Bradley Co. .... Milwaukee 4, Wis.
Allis-Chalmers Mfg. Co. .... Milwaukee 1, Wis.
Ark-Les Switch Corp. .... Watertown, Mass.
Arrow-Hart & Hegeman Electric Co., Hartford 6, Conn.
Automatic Electric Co. (*Fig.* 10) .... Chicago 7, Ill.
Barkelew Electric Mfg. Co. .... Middletown, O.
Carling Electric Inc. (*Fig.* 4), West Hartford 10, Conn.
Carter Parts Co. .... Chicago 10, Ill.
Centralab Div., Globe-Union Inc. (*Figs.* 11 and 13) .... Milwaukee 1, Wis.
Control Products Inc. .... Harrison, N. J.
Cutler-Hammer Inc. .... Milwaukee 1, Wis.
Daven Co. .... Newark 4, N. J.
Electro Switch Corp. .... Weymouth, Mass.
Federal Anti-Capacity Switch Corp. .... Buffalo 8, N. Y.
Furnas Electric Co. .... Batavia, Ill.
General Control Co. (*Figs.* 6, 7 and 9) .... Boston 34, Mass.
General Electric Co. .... Schenectady 5, N. Y.
Oak Mfg. Co. .... Chicago, Ill.
Ohmite Mfg. Co. .... Chicago, Ill.
P. R. Mallory & Co. Inc. (*Figs.* 11 and 12) .... Indianapolis 6, Ind.
Micro Switch Div., Minneapolis-Honeywell Regulator Co. (*Figs.* 2, 3, 5 and 15) .... Freeport, Ill.
Industrial Div., Minneapolis-Honeywell Regulator Co. .... Philadelphia 44, Pa.
Roller-Smith Corp. .... Bethlehem, Pa.
Rowan Controller Co. .... Baltimore, Md.
Shallcross Mfg. Co. .... Collingdale, Pa.
Soreng Products Corp. .... Schiller Park, Ill.
Stackpole Carbon Co. (*Fig.* 14) .... St. Marys, Pa.
Webster-Chicago Corp. .... Chicago 39, Ill.
Westinghouse Electric Corp. .... Pittsburgh 30, Pa.

They Say . . .

"As long as we can keep our scientists and engineers equipped with the instruments we need and working in an atmosphere of freedom, we need not worry about the loss of the old frontiers of opportunity . . . To get some idea of how fast our progress may be in the years ahead, it is helpful to see how far we have come in the last decade and a half. Just consider, for instance, that in 1938 medicine had no antibiotics—and agriculture was without DDT. In that year there was no television industry, no synthetic rubber industry. No one knew how to seed clouds for rain or how to split the uranium atom. And we knew next to nothing about jet aircraft, guided missiles, or electronic computers."—L. L. COLBERT, *president, Chrysler Corp.*

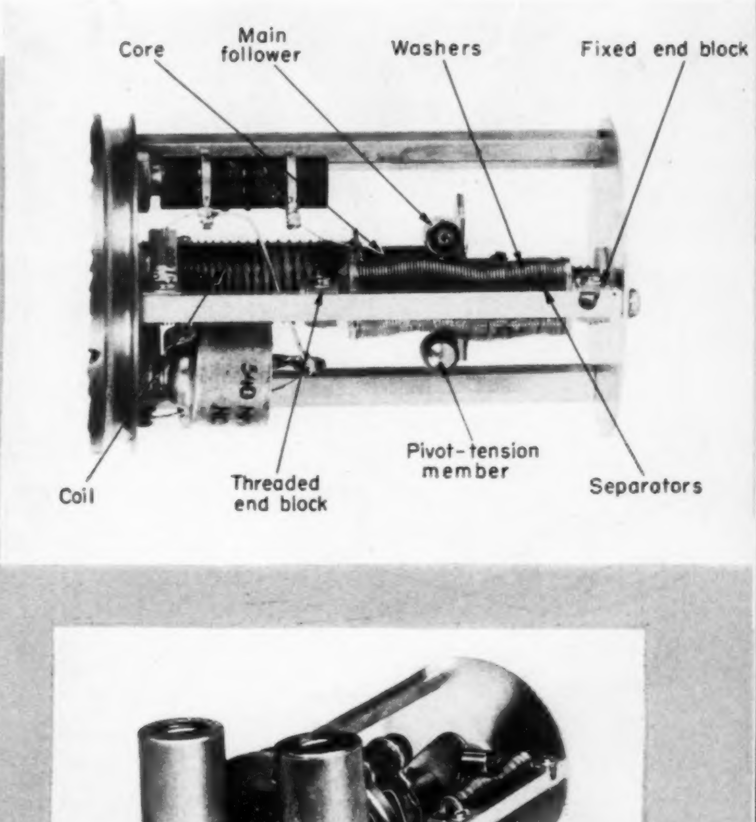
"After years of study and discussion it seems to be agreed that a better balance is needed and can be attained in the engineering colleges between sound training in basic engineering principles, an introduction to some field of specialized engineering technology, some understanding of economics and human relations so important in our complex civilization, and last but not least, the development of skill in communication, in effective writing and speaking."—J. F. FAIRMAN, *vice president, Consolidated Edison Co. of New York, Inc.*

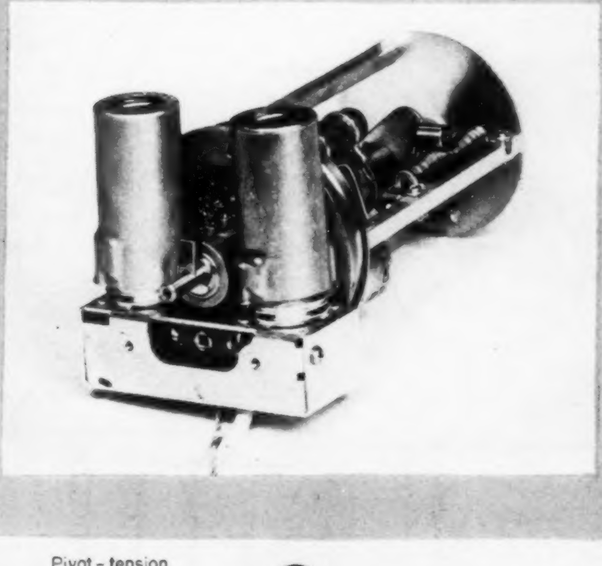
"We do a wonderful job of running the slide rule but only a fair job of interpreting what we are doing to the man who benefits from our labor. We take too much for granted."—A. C. MONTEITH, *vice president in charge of engineering and research, Westinghouse Electric Corp.*

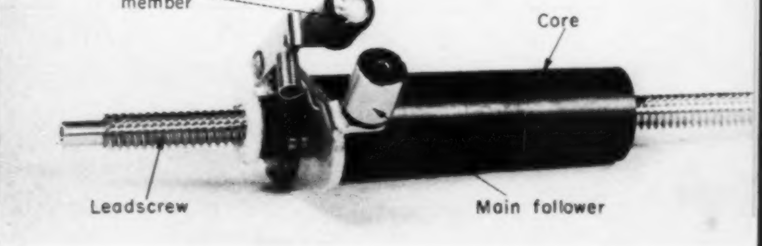
SCANNING the field for IDEAS

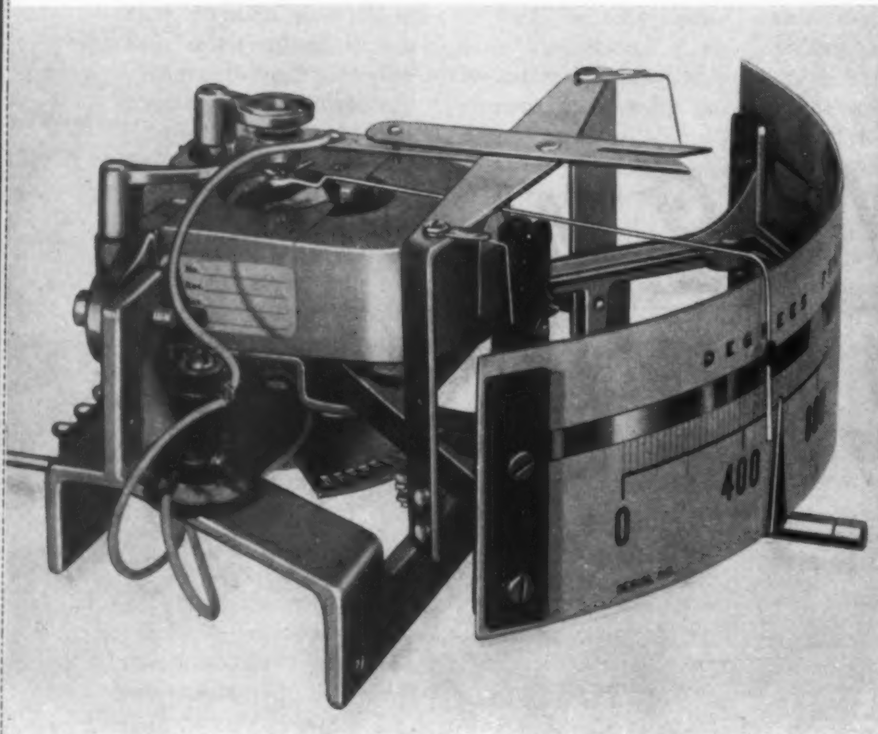
TAILOR-MADE CAM PROFILES from "stacks" of washers facilitate precision adjustment of follower motions to meet application requirements. Developed by Collins Radio Co., a patented corrector mechanism for electronic oscillators employs a number of thin washers, mounted on a shaft, to regulate the linear motion of a core member traveling along a leadscrew. In operation, the contour formed by the edges of the washers serves to impart a differential rotary motion to the moving core, retarding or advancing the rate of linear travel to provide a uniform rate of frequency change as the core passes in and out of a coil.

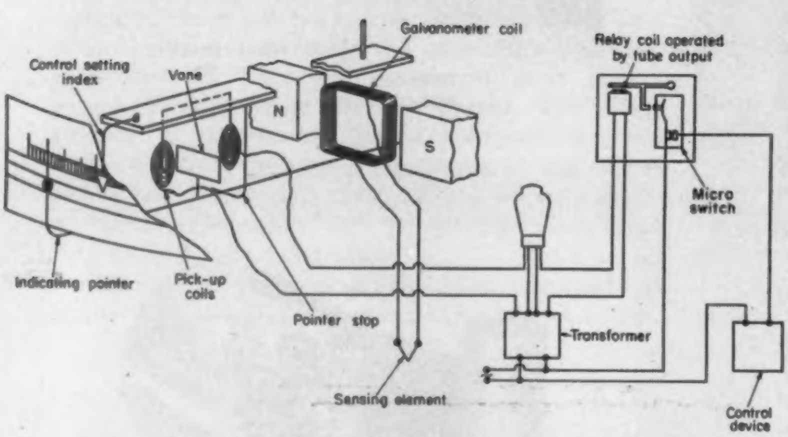
Precise adjustments in the cam contour can be readily obtained through variation of the positions of the individual slotted washers which are of minimum thickness, over 60 washers being required to form a 1½-inch cam edge in the oscillator application. Movement of adjacent washers during the adjustment operation is prevented by thin separators. After adjustment, the washer stack is securely locked in position by means of blocks at each end of the shaft; one block is fixed, the other is threaded to the shaft and free to move. Close engagement of the main follower with the cam contour is assured by a spring-loaded pivoted member, also attached to the moving core, which contacts the side of the cam edge opposite the main follower to provide a clamping action.

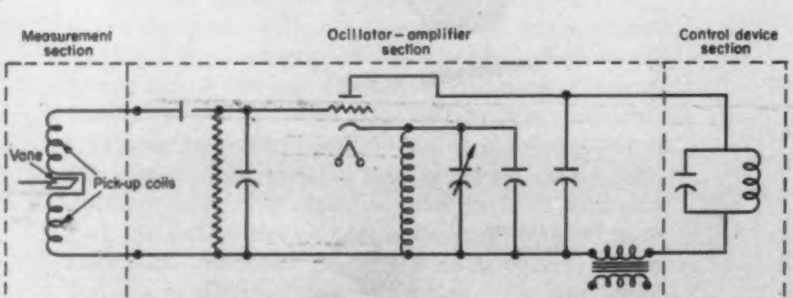










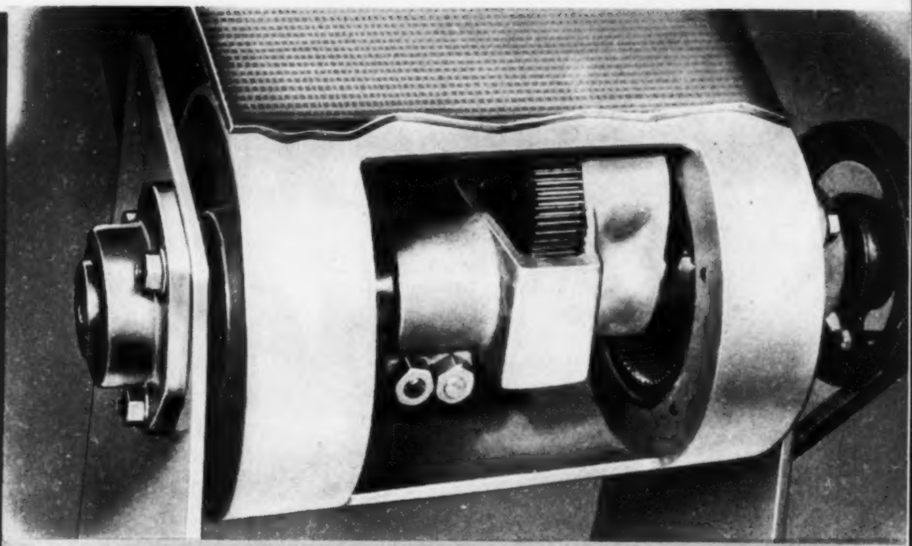


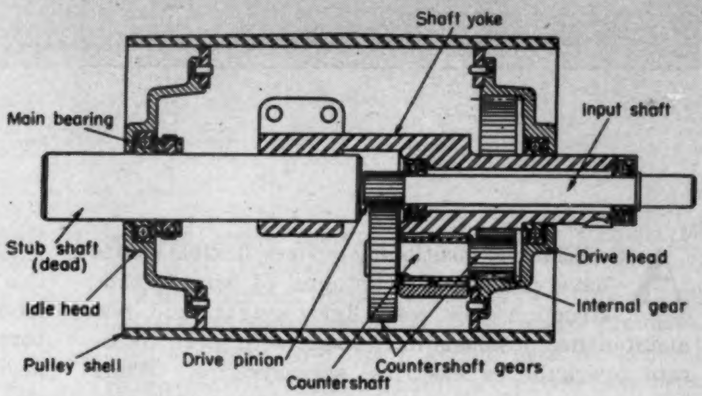
ACCURATE CONTROL of temperature or other process variables is accomplished automatically with an electronic system developed by Wheelco Instruments Div. of Barber Colman Co. Suitable for use with any variable quantity that can be reduced to an electric signal, the system employs a no-contact electronic link between the measuring unit and an oscillator control circuit. Operation of the electronic link is based on the change in inductance produced in two adjacent connected coils by a metallic member passing between the coils.

In this system, a light metallic vane mounted to the indicating pointer arm is free to pass between two pickup coils which are attached to an externally adjustable index arm and form part of the oscillator circuit. Changes in the controlled variable, picked up by an appropriate sensing element, actuate a precision galvanometer to move the indicating pointer across the calibrated dial. As the pointer approaches the control point established by the index arm, the vane passes into the field of the pickup coils, influencing the inductance of the coils to tune or detune the oscillator circuit and regulate the current flow to a relay or other final controlling device. High sensitivity is achieved through the system which provides positive on-off current regulation for vane motions in the order of 0.006-inch around the control point.

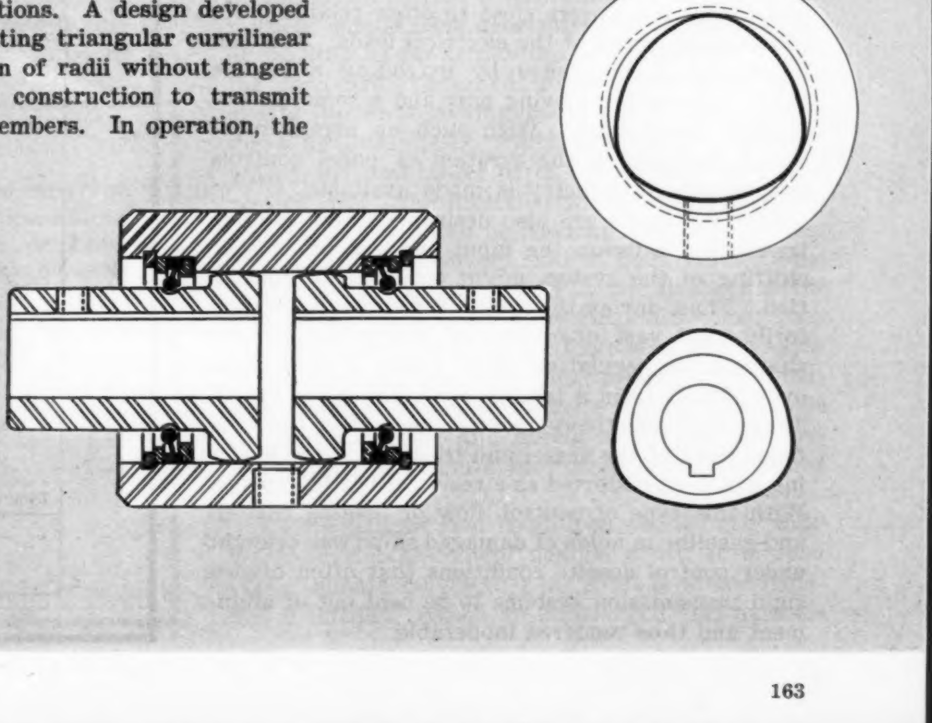
IDEAS

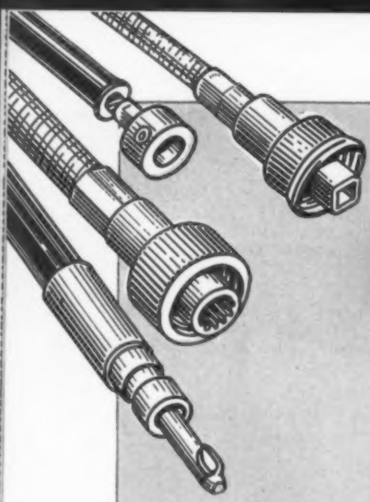
COMBINATION PULLEY - REDUCER minimizes conveyor drive space requirements and offers two-unit performance in a single - mounted assembly. Employed on the Concentro-Drive pulley, a built-in double gear reduction unit eliminates the need for external step-down transmissions or high torque drives and permits direct connection to V-belt drives operating at high speeds. Power transmission is accomplished through a double gear set in which an internal gear, rigidly mounted to the pulley, is driven through two gears in a countershaft arrangement by a pinion on the drive shaft. Modification of V-belt sheave size, pulley size or gear reduction ratios offers flexibility in meeting application requirements.





TRIANGULAR CONTACT SURFACES in a universal coupling increase load capacity and simplify assembly problems in misaligned shaft connections. A design developed by Kerns Mfg. Corp. utilizes mating triangular curvilinear surfaces, based on a combination of radii without tangent flats, in a three-piece coupling construction to transmit power from driving to driven members. In operation, the drive members are self-centering under all load conditions, eliminating eccentricity problems associated with conventional coupling types. Additionally, the design acts to distribute the load over a relatively large bearing contact surface, increasing the joint capacity and efficiency.





FLEXIBLE SHAFTS FOR

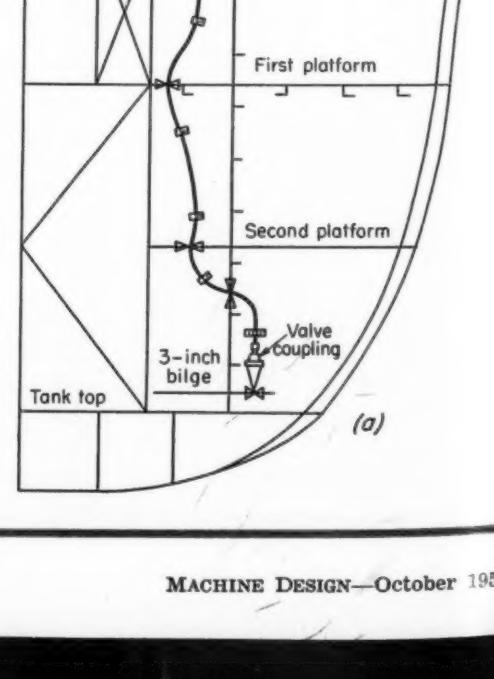
By W. J. Kupfrian
President
Kupfrian Mfg. Co.
Binghamton, N. Y.

AS REMOTE positioning devices, flexible shafts have inherent advantages of simple construction, low cost, light weight, and few maintenance problems in contrast with more elaborate hydraulic or electrical servosystems. While not a panacea for all motion transmission problems, they also offer advantages in certain cases over conventional mechanical systems.

With the current trend toward greater compactness of assemblies, and corresponding reduction in overall dimensions, flexible shafting permits orderly placement of parts to provide high operating efficiency, ready assembly, and convenient servicing. In electronic equipment, for example, it is often desirable to locate switches, potentiometers and tuning condensers close to other related parts to minimize length of the electrical leads. This can be readily accomplished by extending a flexible shaft between the moving part and a remotely positioned panel knob. With such an arrangement design freedom in the position of panel controls and in panel symmetry is made available.

Flexible shafts are also desirable where relative translation between the input and output ends or shifting of the system might occur during operation. Thus, during the last war, the Navy satisfactorily used vast quantities of heavy-duty flexible shafting for regulating large valves often located over 50 feet from a topside control station, *Fig.* 1. These were effectively operated even after the steel framework of the vessel and the path of the shafting had been distorted as a result of battle damage. With this type of control, flow of flaming fuel oil and gasoline in holds of damaged ships was brought under control despite conditions that often caused rigid transmission systems to be bent out of alignment and thus rendered inoperable.

There are, of course, many situations were flexible shafting is unable to meet exacting requirements as to minimum radius of bend, or minimum torsional deflection (often mistakenly called backlash) between input and output ends because of size, weight, and physical strength limitations. In



REMOTE CONTROL

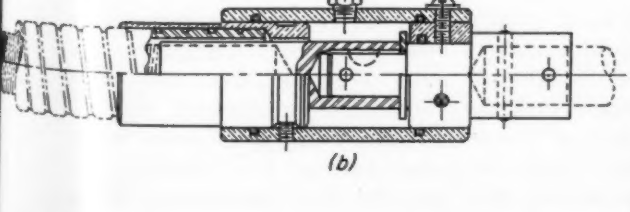
Design considerations in selection and use for control applications

many fields of application, however, flexible shafting offers new opportunities to the designer who has taken some time to become familiar with the possibilities.

Shaft Characteristics: A flexible shaft, or "core" as it is commonly known, consists of multiple wires wrapped helically, layer on layer, usually about a supporting mandrel wire, each such layer being wound in the opposite direction from the preceding layer, *Fig.* 2.

Remote-control shafts ordinarily vary in diameter from ⅛-inch on light-duty hand-operated knob controls having a torque capacity of a few pound-inches, to sturdy windings of high-tensile music wire with diameters exceeding 1½-inches that are either operated by massive handwheels taxing the full strength of the operator, or actuated by reversible prime movers for delivering torques of over 3000 pound-inches.

Fig. 1—Heavy-duty remote-control flexible shaft on ships, *a*, operates below-decks valves from topside area. Typical terminal, *b*, connects valve stems or handwheels to flexible shafting up to 1⅝ inch diameter



(b)

Within normal limits, properties of a core can be ascertained quite accurately. Standard products, such as shown in *Table* 1, should meet all general requirements. Standard shaft properties have been well established by extensive use. Where specific flexible shafting having special properties is required, it may be prepared by varying the number of layers of wire, number of wires in each layer, wire diameters in adjoining layers, type or composition of the wire, and tension employed during winding operations.

Most remote-control applications have load conditions approximately the same for both directions of operation, so that a well-designed shaft for this purpose should have generally uniform bidirectional qualities as far as torsional deflection and breaking load are concerned, *Fig.* 3. Remote-control shafts should be distinguished clearly from power-drive flexible shafts, which are usually designed with fewer and larger wires for rotation in one direction only—the direction which causes the outside layer to tighten or wind up during operation. These shafts, however, exhibit poor bidirectional properties, are characterized by low strength in the unwind direction and high angular deflection. They should be avoided in normal remote-control applications. Experimenters who, wittingly or otherwise, attempt to apply the more readily procurable speedometer shaft and casing as a light duty remote-control shaft are inevitably disturbed at the poor results.

With equalized load conditions and a fairly well-balanced remote-control flexible shaft, it is relatively immaterial whether the shaft is wound right-lay or left-lay. When an unbalanced load exists—

Table 1—Typical Flexible Shaft Properties

Nominal Shaft Diameter (in.)	Material	Maximum Recommended Torque (lb-in.)	—Torsional Deflection— (deg/in./lb-in.) Wind	Unwind	Breaking Load (lb-in.) Wind	Unwind	Minimum Operating Radius (in.)	Torque to Rotate 90 Degrees (lb-in.)	Radius (in.)
0.130	Monel	3.5	0.96	1.3	14	12	3½	0.133	4
0.130	Steel	5	1.0	1.5	14	11	3¼	0.065	4
0.130	Bronze	1.5	1.5	7	10	4	3¼	0.080	4
0.130	Bronze	3.5	1.8	2.6	15	9	3½	0.250	5
0.150	Steel	7	0.5	0.5	18	17	3	0.100	4
0.150	Bronze	5	2.7	2.7	18	13	4	0.130	4
0.150	Bronze	7	0.8	1.0	25	17	3½	0.090	5
0.150	Monel	7	0.7	0.9	22	17	3	....	..
0.187	Steel	15	0.3	0.36	50	36	4	0.150	6
0.187	Monel	7	0.57	0.45	28	21	4	0.120	6
0.187	Steel	15	0.45	0.55	50	32	3	0.060	5
0.187	Bronze	12	0.40	0.48	31	28	4	0.120	5
0.212	Steel	13	0.27	0.29	48	40	4	0.154	6
0.250	Steel	40	0.15	0.17	150	130	4	0.350	6
0.310	Steel	60	0.03	0.08	160	90	6	....	..
0.375	Steel	100	0.025	0.035	381	278	8	....	..

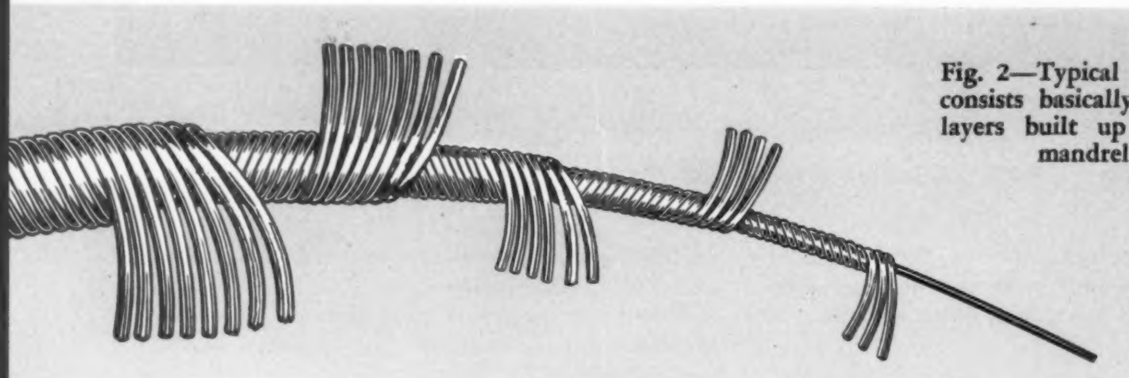


Fig. 2—Typical flexible shaft consists basically of alternate layers built up from single mandrel wire

where spring action, weight, wind forces, or similar conditions favor operation in one direction—the designer can obtain distinct advantages in choice of the shaft by specifying load conditions for each direction of rotation. These directions are usually designated as *clockwise* or *counterclockwise* when looking along the shaft from the power end. A shaft is thereby obtained with properties matching the load conditions.

Operating efficiency of the flexible shaft is determined largely by its internal friction. This characteristic is usually listed among the physical properties, in terms of the torque required to rotate the shaft through a stipulated, relatively short radius of bend, and an included angle of either 90 or 180 degrees. In many instances, such as where light loads or infrequent operation are encountered, internal friction is not a material factor, particularly if the shaft is not in a cramped position. These internal losses, however, affect endurance limit stresses that can be applied, and they may materially shorten useful life where the application is powered, or affect smoothness of operation on hand-operated assemblies where radius of bend is small and loads heavy. Ordinarily, torque ratings describe a maximum recommended torque for the ideal, substantially straight-line operating condition, with progressively lower torque ratings as the operating radius decreases to a stipulated minimum.

Primary Design Considerations: Desired physical properties of the flexible shaft required for a project should be established as a natural first step in the selection of a standard unit. Primary considerations include torque to be transmitted, torsional deflection or yield angle that can be tolerated at full load, minimum operating radius to which the shaft must be curved, and principal direction of rotation if the load is unbalanced.

TORQUE REQUIREMENTS: Torque required to operate most manually rotated devices is frequently best determined experimentally. One simple method consists of attaching a pulley, knob or dial of known radius to the shaft of the driven member, wrapping a piece of strong thread, fish line, or steel strand about the pulley, and exerting a tension with standard weights or with a spring scale to produce the desired motion. A lever clamped or pinned to the shaft may substitute for the pulley, and a small notch in the lever at the desired radius may be used to locate the spring scale. Of course the scale must be moved as the part rotates to maintain correct load direction. Extending the lever equally in both directions from the shaft compensates for unbalance introduced by the weight of the lever itself. For moderately heavy loads, toggle wrenches clamped in a vertical position on the shaft are effective, particularly where rotary motion is slight so the wrench remains in a relatively balanced position.

In obtaining such a torque value, adequate allowance should be made for any additional factors, as inertia effects, acceleration forces, or additional frictional losses that might result from high or low ambient temperature conditions. Additional losses from internal friction, and friction between core and casing, will develop if exceptionally long assemblies or small operating radii are involved. Many flexible shaft manufacturers in their shaft specifications make a substantial allowance for safety factor by recommending a maximum safe load of approximately 25 per cent of the breaking load for power-drive applications, though higher values can be used on remote-control applications where heating or fatigue conditions do not exist. On complicated applications, a prototype unit tested under actual operating conditions is effective in resolving questionable parameters.

TORSIONAL DEFLECTION: Although a flexible shaft strong enough to meet the torque requirements may be selected, torsional deflection properties may be found to be excessive for the application, indicating the need for a stiffer (and stronger) shaft. Charts are usually available for standard flexible shafts showing the angular deflection that can be expected in degrees per unit of length for any torque load condition, for both winding and unwinding directions, *Fig.* 3. Where this information is not available, it is a simple matter to calculate the deflection from published data, since shaft deflection usually varies almost in direct proportion to the applied load, following Hooke's Law.

Most tables of shaft properties show the angle of torsional deflection at unit load and over a unit length, so that multiplication of that factor by desired torque and by desired length of the flexible shaft assembly gives approximate total deflection angle. Hence, a shaft picked on the basis of strength alone should be checked to determine how much deflection might be expected, and if the angle is found to be excessive a stronger shaft with the required deflection properties should be selected.

If strict deflection requirements impose intolerable shaft size requirements, consideration should be given to reduction in length of the flexible shaft. This reduction can be accomplished by extending the rigid input or output shafts until the two ends to be joined are closer together, thereby reducing the deflection angle of the flexible shaft. Or a motion amplifying mechanism might be considered to reduce the torque requirements. Conventional belts and pulley or gear-train mechanisms are often thus used. In this type of setup the flexible shaft should always be installed in the portion of the system operating at higher speed.

It should be borne in mind that if controls are expected to operate in both directions, combined deflection angle is the sum of the two angles resulting from operating the shaft first in the windup and then in the unwind direction from no-load to full-load positions. The designer should establish as liberal deflection requirements as possible in the interests of keeping size, weight and cost of the shaft to a minimum.

MINIMUM OPERATING RADIUS: Assuming that a selected shaft meets the torque and deflection requirements, the required operating curvature of the shaft should be checked as to minimum operating radius. Although, in some instances, a shaft may be operated about smaller radii than recommended, the application should be checked very carefully. These sharper bends create additional internal stresses in the shaft which, in effect, increase the applied load and may in turn affect normal operation. Most shafts can be compressed into a loop under mild pressure to a definite resistance point, and the distance across the resulting circle often is referred to as the "loop diameter." In this condition, the curvature is too tight for nor-

Fig. 3—Torque-deflection properties of heavy-duty remote-control shafting

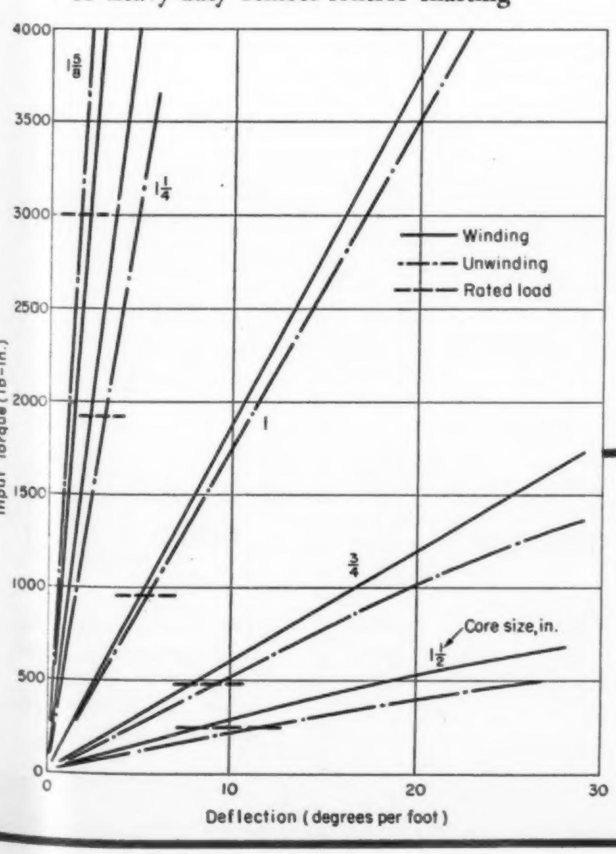
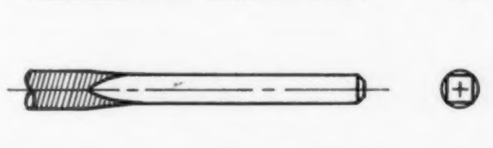


Fig. 4—Hexagonal or square crimped shaft ends form inexpensive terminals for spline or set-screw connections

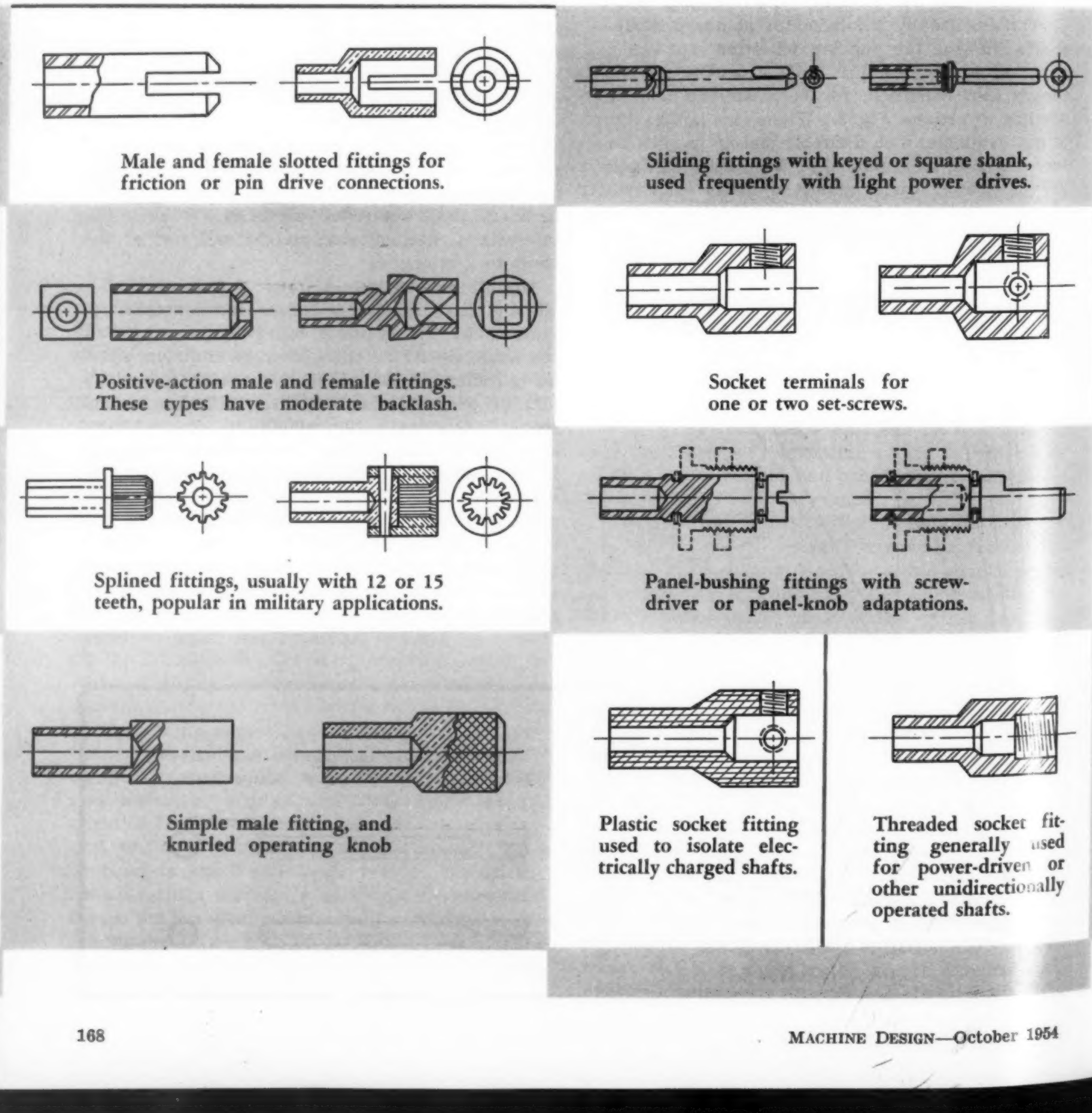


mal operation. As a rule of thumb, however, most shafts can be operated safely when the loop is opened up 100 per cent until the radius roughly equals the "loop diameter." Minimum operating radius requirements should be relaxed to permit the largest radius consistent with good design, thereby reducing frictional losses, increasing useful shaft life, and providing smoother operation.

Direction of Rotation: Most remote-control flexible shafts are designed to exhibit similar properties in either direction of operation. Hence, it is ordinarily unnecessary to consider the direction of rotation or, conversely, to consider whether the outer layer of the shaft is right or left lay. In some installations, however, the weight of the operated part, a preloading spring or other similar conditions tend to unbalance the load. This is of concern, since it may permit utilization of a shaft having unbalanced properties that correspond with the unbalanced load, thereby offering possible advantages in cost and weight reduction. Of course, for maximum performance on power-driven assemblies intended for unidirectional operation, direction of rotation always should be specified to allow the use of a shaft of the proper lay, specifically one whose outer layer tends to tighten or wind up during normal operation.

Special Considerations: Additional physical conditions may affect the choice of a flexible shaft. Typical of these is maximum length of shaft assembly, where the shaft must extend over an unusual distance. In the great bulk of remote-control applications, length falls in the range of several

Fig. 5—Typical Shaft Terminals



Male and female slotted fittings for friction or pin drive connections.

Sliding fittings with keyed or square shank, used frequently with light power drives.

Positive-action male and female fittings. These types have moderate backlash.

Socket terminals for one or two set-screws.

Splined fittings, usually with 12 or 15 teeth, popular in military applications.

Panel-bushing fittings with screwdriver or panel-knob adaptations.

Simple male fitting, and knurled operating knob

Plastic socket fitting used to isolate electrically charged shafts.

Threaded socket fitting generally used for power-driven or other unidirectionally operated shafts.

inches to several feet. Instances are known, however, where shafts have been successfully operated over distances of 150 feet, particularly where the output load is light, as in telemetering systems, and especially where speed multipliers are used. In one such mechanical signal extending between the bridge and engine room of a vessel, an indicating receiver was effectively operated by a ½-inch diameter shaft through a 6 to 1 gear train from a point 150 feet distant with accumulated bends of 720 degrees between input and output ends. In Navy remote-control valve applications previously referred to, it is common to deliver torques up to 3000 lb-in. over distances of 50 feet, even where numerous standard-radius curves are present. Longer lengths and additional or tighter curves introduce higher load factors, requiring a larger shaft.

Also, if the flexible shaft is intended to operate at relatively high speeds where fatigue problems or heating effects might be present, such as in a reversible servomechanism, the shaft must operate within endurance limits. In some heavier installations, load stresses have been measured successfully with dynamic strain gages.

Unusual Operating Conditions: The common or garden variety of flexible shaft is designed to operate under normal atmospheric and temperature conditions within a weather-protected area. In the presence of high or low temperatures, corrosive fumes or moisture, flexible shaft materials should be selected to meet such conditions properly. K-Monel, bronze and stainless steel, or a combination of them, are generally used under such conditions for the core and casing construction. A plasticized vinyl cover frequently is used on the casing for more complete protection, electrical insulation, better appearance, or resistance to corrosive reagents and greases where temperature conditions permit (between −65 and 150 F).

Thin yellow brass sections should be avoided on uncovered casings, particularly in the presence of salt water or other chlorides, since these chemicals tend to dezincify the metal, and excessive vibration tends to cause age embrittlement. Stainless steel of the usual type 302 variety also shows some susceptibility to attack by salt water, particularly in the case of repeated immersions. Bronze and Monel are to be preferred in such cases.

Bronze cores are not particularly suited to high-temperature applications, and the material's substantially lower modulus of elasticity results in a shaft with relatively poor deflection properties. Type 302 spring-temper stainless steel and K-Monel both operate at temperatures up to 500 F without marked reduction in strength, or endurance properties, though lubrication may require special attention. Both materials are highly resistant to action by most chemicals.

In many military and electronic installations, the flexible shaft construction is required to be nonmagnetic. Bronze or K-Monel shafts are commonly employed in such installations with casings of brass, bronze or aluminum. Aluminum casing finds special favor in airborne installations, but suffers from poor corrosion and wear resistance. Type 302 stainless steel, though an austenitic alloy, becomes magnetically permeable through cold working and is unacceptable as a nonmagnetic material. The core may be annealed to eliminate cold working effects, but this action may reduce shaft strength by more than 50 per cent. Special austenitic wires have been developed in the stainless steel group, however, whose magnetic permeability remains close to unity even after considerable cold forming, such as is incident to drawing and shaft-

Fig. 6—Flexible-shaft coupling (without casing) as applied to connect a remote panel control knob with potentiometer tuning shaft, switch, or similar component

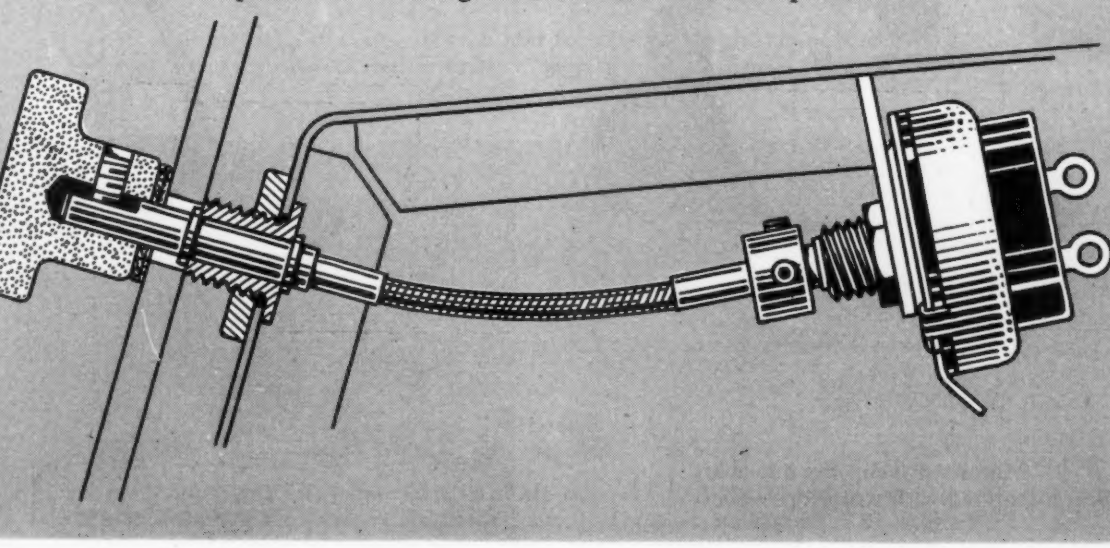
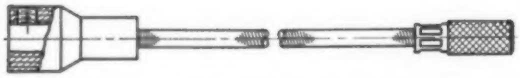


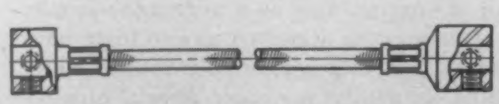
Fig. 7—Common Flexible-Shaft Couplings

Coupling for shaft operation from a remote instrument panel knob.

Screw-driver panel control, used for preset instruments where adjustment is infrequent.



Coupling using a plastic terminal for electrically insulating a "hot" chassis shaft from the "built-in" diamond-knurled metal operating knob at the other end.



Coupling for connecting shafts of same or unequal diameters.

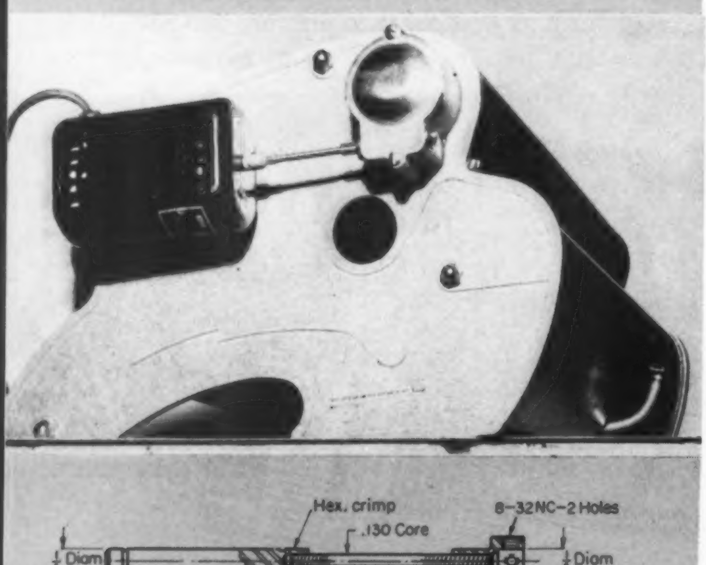


Fig. 8 — Motor-driven flexible-shaft coupling integrated with worm drive-shaft

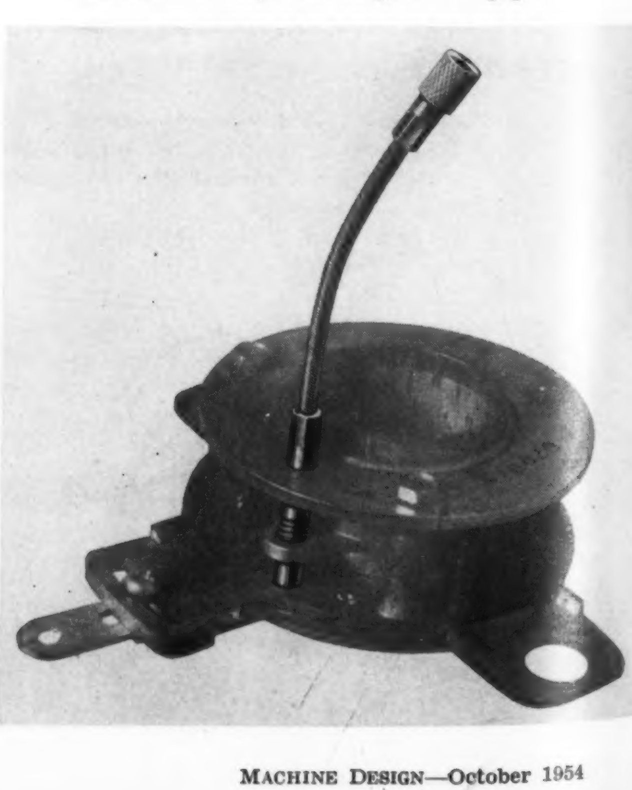
coiling operations. However, for nonmagnetic core operation, K-Monel is considered a preferred material by many manufacturers.

Selection of Terminals: Core terminals are the means employed for attaching the flexible shaft to the driving and driven members. Perhaps the simplest end connection is merely a portion of the core itself, deformed at one or both ends to square or hexagonal cross section, *Fig.* 4, for insertion in a correspondingly formed socket member. A similar expedient is to insert the deformed end into a closely fitting round socket in the driving or driven member, and to hold the part firmly in place with one or more set screws. To avoid unraveling of the wires by the set screw, it is customary to hold the wires firmly in place with solder or, better yet, by fusing the shaft end electrically during the cutting operation.

Perhaps the most popular single type of separate core fitting comprises a round socketed metal member that is swaged, crimped or otherwise attached to the core end, with one or more set screws extending through the wall of the fitting for engagement with the driving or driven shafts. Most manufacturers produce a number of available core fitting types for the more popular sizes of core, from which the designer may select the type most suited to his needs. Typical examples are shown in *Fig.* 5.

Soft soldering of fittings is rarely used except for small quantities, and is little used in preference

Fig. 9 — Remote-control permanent-magnet focuser for television tubes, utilizing a flexible-shaft coupling. A lead screw at the output end transforms rotary shaft motion to linear axial motion to vary the magnet air gap

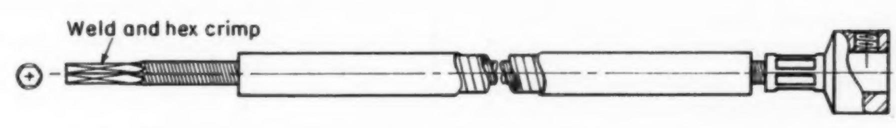


to swaging or crimping for production runs because of excessive cost. Silver soldering should be avoided except for special requirements, not only because of high material and labor cost, but also because the relatively high temperatures involved heat adjoining exposed shaft portions excessively, causing substantial loss in strength.

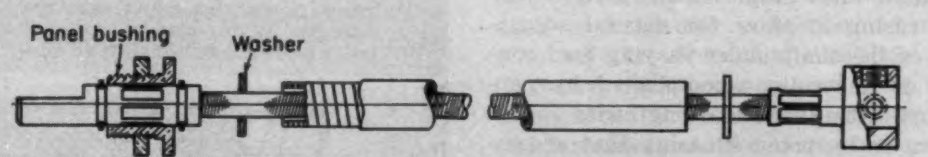
Most flexible shafts are wound with the wires essentially under initial tension which causes the shaft to unravel when it is cut unless special precautions are taken. To insure proper tension in the wires and normal shaft performance, the cutting operation should be performed only with reliable equipment and by experienced personnnel. This operation normally is performed by the shaft manufacturer.

A popular type of end fitting used extensively for military purposes comprises a small internal gear having 12 teeth with a ¼-inch pitch diameter (48 diametral pitch) for engagement with a small 12-tooth gear formed from pinion stock and extending from the driving and driven members. Threaded shaft terminals are frequently used on power-drive applications but are not satisfactory

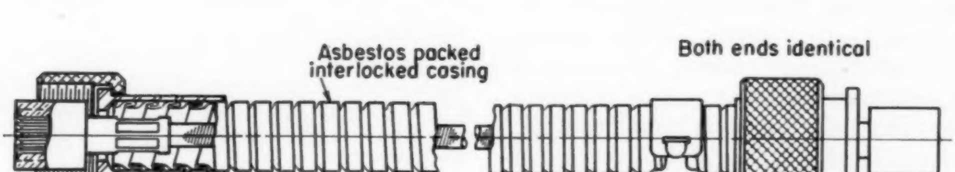
Fig. 10—Typical Shaft Assemblies



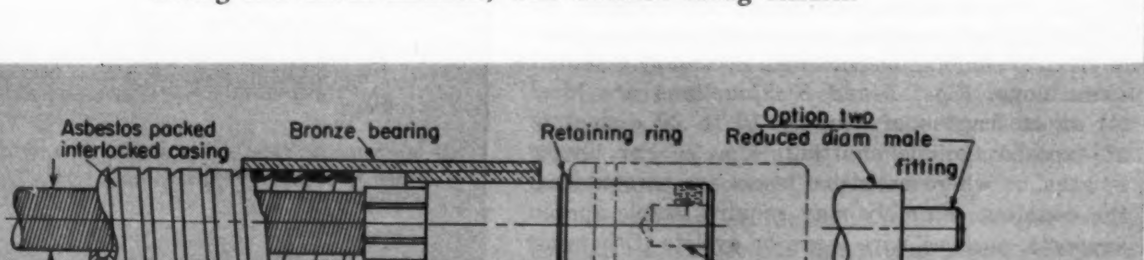
Hexagonally crimped end for sliding or set-screw connection to a socketed member. Opposite end has a set-screw connection.



Panel bushing and slotted male shaft for push-on knob or set-screw held dial. Set-screw connection on opposite end.



Internal gear fitting at each end for connection to pinion-stock driving and driven members, with threaded casing ferrules.



Self-contained and journaled flexible shaft with floating shaft fittings, showing various terminal connections (large and small socket or male shaft connections)

for bidirectional operation. Cylindrical fittings formed with a radially projecting key are sometimes used, as are fittings with square sockets or square shanks, particularly where slight blacklash in the joint can be tolerated. In some cases male or female fittings are slotted longitudinally to allow for resilient frictional engagement with the mating part, sometimes with wire projections extending through the slot for positive driving action. Occasionally a flexible shaft requires tight connection at both ends and yet must be capable of slight length variation during operation, a condition satisfied by using a complete fitting with telescoping inner and outer parts and with cooperative pins and slots or keyways.

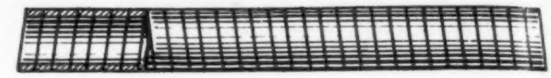
Standard materials for fittings comprise steel with cadmium or zinc plating, plain or nickel-plated brass, and stainless steel. Phosphated or chromated cadmium or zinc coatings are usually available for additional corrosion resistance, particularly for military specifications. The same fitting is often offered in more than one material. Acetate and other similar thermoplastic materials are sometimes attached by a combination of heat, cement or pressure and are used where electrical insulation is required, particularly in connection with television or other electronic installations having a "hot" chassis.

With power-driven flexible shafts it is common to provide relative endwise movement between the core and the casing to allow for natural adjustment or float of the shaft under varying load conditions. This is generally accomplished by permitting the end fitting to slide lengthwise in the end connection, or by using a casing that accommodates for length. With remote-control shafts, however, it is more customary to secure the shaft and the casing without provision for end play, which accounts for the popular use of set screws in the end connections. Panel bushings also are generally available for use with standard $\frac{1}{4}$-inch diameter male shaft fittings, allowing a convenient method for journaling the input end to a control panel for operation by a control knob or screwdriver, *Figs*. 6 and 7.

Casing Selection: Under certain circumstances a flexible shaft may be operated without a casing, *Fig*. 6. The resulting assembly, often known as a flexible-shaft coupling, consists of merely a piece of flexible shafting or core with necessary terminal connections, *Figs*. 7 and 8. Couplings are ideal for short lengths of roughly 10 to 20 diameters of exposed flexible shafting, *Fig*. 9. For longer lengths, or where extensive bends are encountered, the coupling assembly may require simple spaced supports, such as wire loops or eyelets. Otherwise the shaft should be encased to form a complete flexible shaft assembly, *Fig*. 10.

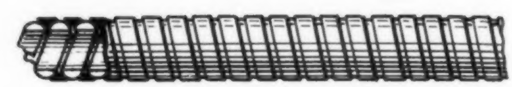
Casings are generally used primarily to increase torque capacity of a shaft by minimizing its tendency to helix under load. A casing is otherwise used to support the shaft more adequately, to protect it from damage and corrosion, and to help

Fig. 11—Typical Casings

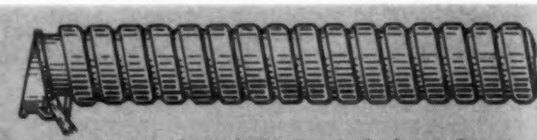


a—Single flat-wire Monocoil casing. Designed for light-duty work, this type of casing is inexpensive. It is usually available in a number of metals, including galvanized steel, brass, stainless steel or bronze.

b—Same as type *a* but with an extruded vinyl cover. Popular for general use, this type is watertight and corrosion resistant.

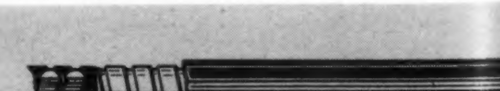


c—Two and four-wire (annealed and drawn) casing for general application where tightness is not essential. Typical materials are galvanized steel and bronze.



d—Square-locked or fully interlocked metal casing, asbestos packed for water tightness. Generally lighter than type *c*, this kind of casing is usually weaker and less wear-resistant. Galvanized steel; aluminum; bronze

e—Braided type consisting of a metal liner with one or more metal braids for stretch resistance and protection. These are popular in military applications but are heavier and more expensive.



f—Same as type *c* with vinyl cover for better lubricant retention, more attractive appearance and electrical insulation. Durable, strong and moderately priced.

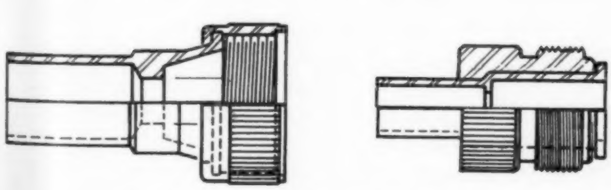
g—Same as type *d* but having one or more layers of wire braid for extra strength. Used in military applications.

h—Same as type *c* with varnished fabric-braided cover for extra strength and water tightness.

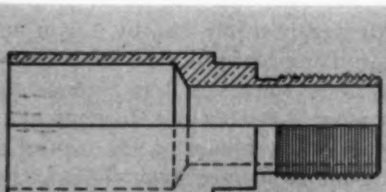
retain the shaft lubricant. Casings are usually of metal—spring steel, bronze, stainless steel or aluminum. Inexpensive types comprise a single wire helix sometimes known as Monocoil, interlocked types formed of specially shaped metal strip, and two-wire and four-wire nested annealed and drawn shaped wires of the type popularly used for speedometer casing, *Fig.* 11. Most of these types are available with a plastic or varnished fabric-braid cover for additional strength, water tightness, corrosion resistance and improved appearance, or with one or more layers of metal braid for improved stretch resistance and added mechanical protection.

Ends of the casing often do not require independent terminal mountings, especially where the lighter, simpler types are used. Where the shaft is not sharply bent near the end, so that appreciable side thrust on the end of the casing does not cause it to bear against the core, terminal mountings may also be unnecessary. In such instances the casing simply floats on the shaft, with a slight space allowed axially at each end of the shaft to provide some length adjustment where the casing tends to elongate from bending. Side thrust due to shaft bending may be overcome by means of a simple clamp near each end to align the casing concentric with the core at the end regions. Often, however, to provide more adequate casing support, less drag on the core, better sealing of the lubricant and more shaft protection, the casing is mounted independently at each end with casing ferrules and nuts. Where a casing is exposed to repeated side thrust near the ends, it may be desirable to use a strain relief consisting of a simple outer reinforcing such as an open helical spring.

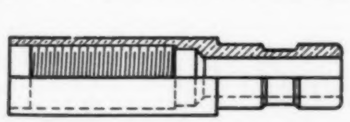
Fig. 12—Ferrules



Female and male swivel nuts and casing ferrule assemblies.



Casing ferrule with integral threaded supporting boss.

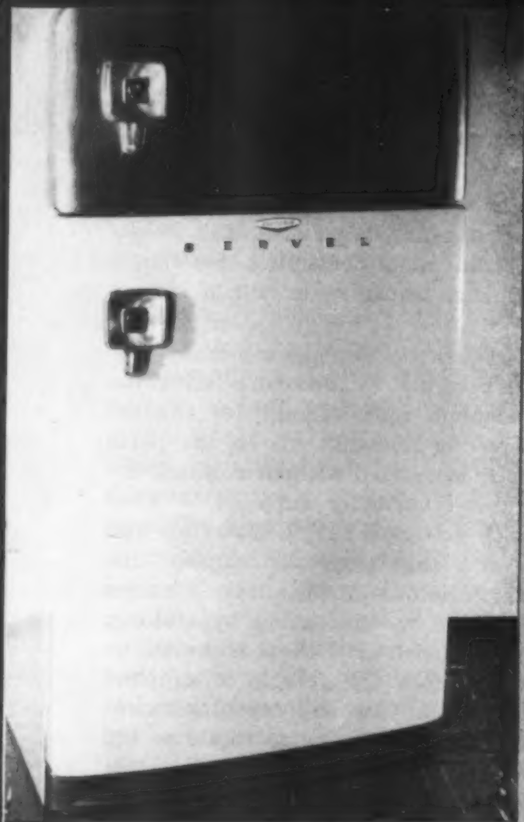


Ferrule with threaded socket for receiving a resilient casing, and reduced-diameter sliding connector with annular set-screw groove.

Casing End Connections: Ferrules generally consist of a tubular member for accommodating the casing with a terminal radial flange for engagement with a swiveling nut that allows the parts to be engaged and disengaged without rotating the casing. Ferrules are normally supplied in sizes corresponding with standard casing materials and with matching nuts that generally employ fine series threads to minimize wall thickness. Ferrules are generally attached to the casing by staking, crimping or swaging, with or without a cement or sealing compound. Often the ferrule is supplied with integral threads at one end for attachment to a support, requiring the casing to rotate as the parts are assembled, or the ferrule may be made to slide into a cylindrical socket or onto a boss where it may be held by a set-screw, *Fig.* 12. Minimum inside diameter of the ferrule is usually not smaller than the inside diameter of the casing, so as not to interfere with removal of the core from the case. Nuts are commonly provided with a knurled surface for hand tightening, or with hexagon or octagon cross sections where a wrench is required. In aircraft applications and wherever excessive vibration is present, holes may be drilled through the nut for retaining wires. Use of nuts and ferrules permits a closer hermetic seal of the assembly. Gaskets and sealing rings sometimes are used in the end connections for tighter joints.

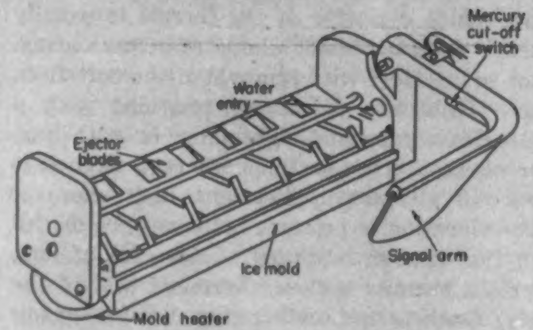
Lubrication: With most hand-operated flexible shaft assemblies, lubrication does not become a very important consideration. Most casings have a hard metallic liner that reduces spalling tendencies, even on power-driven installations. Nevertheless it is customary for the flexible shaft manufacturers to apply a coating of light grease to the shaft during assembly. Special greases can be used to meet the need for high or low operating temperatures. On most remote control applications there is little or no need for maintenance unless the lubricant should become gummy or carbonized. Nevertheless it is considered good design, where convenient, to employ one shaft fitting of small diameter, or of a two-piece construction, so the parts may be separated for cleaning relubrication and, where necessary, replacement.

Occasionally, as for some military requirement, a shaft is required to operate at higher temperatures, typically 500 F. Greases do not operate satisfactorily at these high temperatures, but a number of new lubricants have recently become available for this type of service. Among these may be mentioned the dry types, using films of molybdenum disulphide, tetrafluoroethylene suspensions, and silicone-base materials.



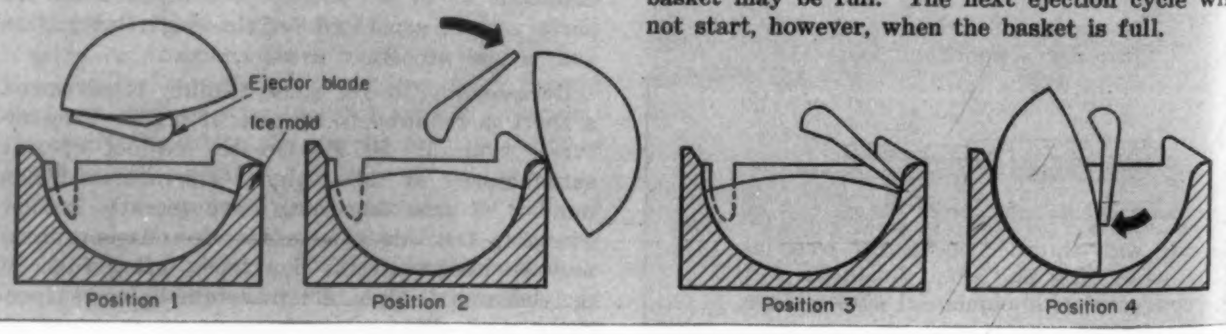
Automatic Ice-Making Refrigerator Has Copper Door

FREEZER compartment door and scuff plate of one of Servel's "automatic ice maker" refrigerators are plated with satin burnished copper. Styled by Reinecke and Associates, the refrigerator is said to be the latest home equipment to join what has been described as "a booming style trend to copper." In addition to attractive appearance, a novel ice-making apparatus is used in the new refrigerator. No filling or emptying of conventional ice cube trays is necessary since the ice maker automatically keeps an ice cube basket filled and, of course, stops making ice when the basket is filled.



Seven nearly semicircular pieces of ice, called IceCircles by the manufacturer, are frozen at one time in the ice mold. Largely of cast aluminum, one end of the mold is plastic, assuring that the ice cube at that end will be the last to freeze because of the differing thermal properties of plastic and aluminum. A thermostatic insert in the plastic end controls a mold heater to loosen ice in the mold and a motor which drives ice-removing or ejector blades. One end of the signal arm on which a mercury switch is mounted rests on the IceCircles in the basket. A full basket causes the mercury switch to break contact and stop the ice-making operation until enough ice has been used to lower the level.

Freezing cycle starts when ice in contact with plastic end of tray is frozen. In the meantime, previously frozen circle has been held above the tray by the ejector blade to dry, position 1, thereby preventing sticking or freezing together of circles in the basket. Freezing of the last circle turns on mold heater to melt circles loose and starts a motor which drives the ejector blades. As ejector blades revolve, dried circles fall into the basket, position 2. Cams on motor shaft close mold inlet water valve, stop the compressor, energize the mold thermostat reset heater and open the water metering tank inlet valve while IceCircles are being delivered to the basket. When ejector blades rotate far enough to contact ice in the tray, position 3, the motor stalls until the mold heater frees the ice. As soon as the ice is free, ejector blades begin to sweep ice from the mold and a cam on the motor shaft closes the metering tank inlet valve. When ejector blades reach position 4, signal arm is lifted by a cam on the ejector blade shaft, breaking the contact of the mercury switch on the arm. If the mold thermostat has not reset at this time, the motor and heater are turned off until the thermostat resets. Rotation then continues, allowing the signal arm to drop, moving ice to drying position and, by a cam on the motor shaft, admitting water to the mold from the metering tank. When position 1 is reached again, ice maker motor, mold heater and thermostat reset heater are turned off by a cam on the motor shaft and the compressor is started even though the ice basket may be full. The next ejection cycle will not start, however, when the basket is full.



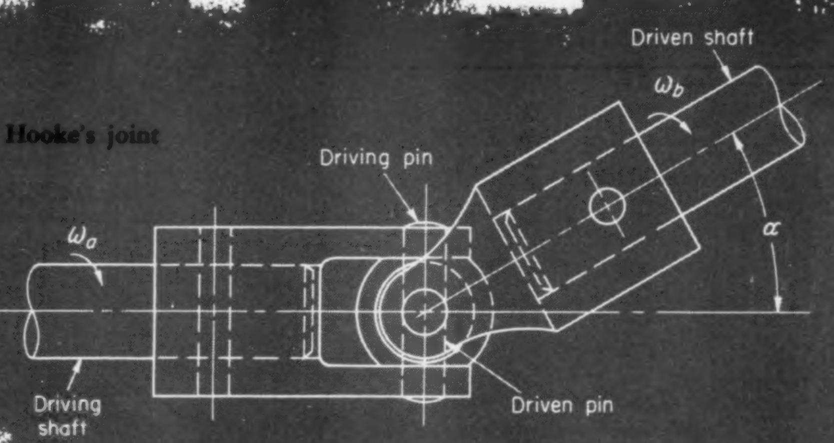


Fig. 1—Single Hooke's joint

How to obtain useful speed variations with UNIVERSAL JOINTS

By Oliver Saari
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Chicago, Ill.

MACHINE designers are sometimes confronted with the problem of obtaining rotation with cyclically varying speed. Sometimes the object is to speed up the operation of a machine, where a large part of the operating cycle would otherwise be idle time. Occasionally a varying speed is used to cancel out undesired variations from the motion of some other part of the mechanism. One simple way of obtaining varying angular motion is with universal (or Hooke's) joints, which have the following advantages over some of the other ways:

1. They are inexpensive items, stocked by many vendors.
2. They can serve the double purpose of permitting misalignment of driving and driven shafts and providing the desired amount of angular speed variation.
3. They are compact and easily installed.

A typical construction for a single Hooke's joint is shown in *Fig.* 1. The speed variations of a single joint of this kind are described in many handbooks and texts, but the formulas will be included here for completeness.

Let θ_a be the angular displacement of the driving shaft from the "zero" position shown in *Fig.* 1. It is convenient to deal with the ratio ω_b/ω_a, which varies with θ_a as follows:

$$\frac{\omega_b}{\omega_a} = \frac{\cos \alpha}{1 - \sin^2 \alpha \cos^2 \theta_a} \quad \text{(1)}$$

Speed ω_b of the driven shaft varies from a maximum value of $\omega_a \sec \alpha$ when $\theta_a = 0$, 180, 360 degrees, etc., to a minimum value of $\omega_a \cos \alpha$ when $\theta_a = 90$, 270 degrees, etc. The speed variation goes through two complete identical cycles in one turn of the driving shaft. The ratio of maximum to minimum output speed is $\sec^2\alpha$.

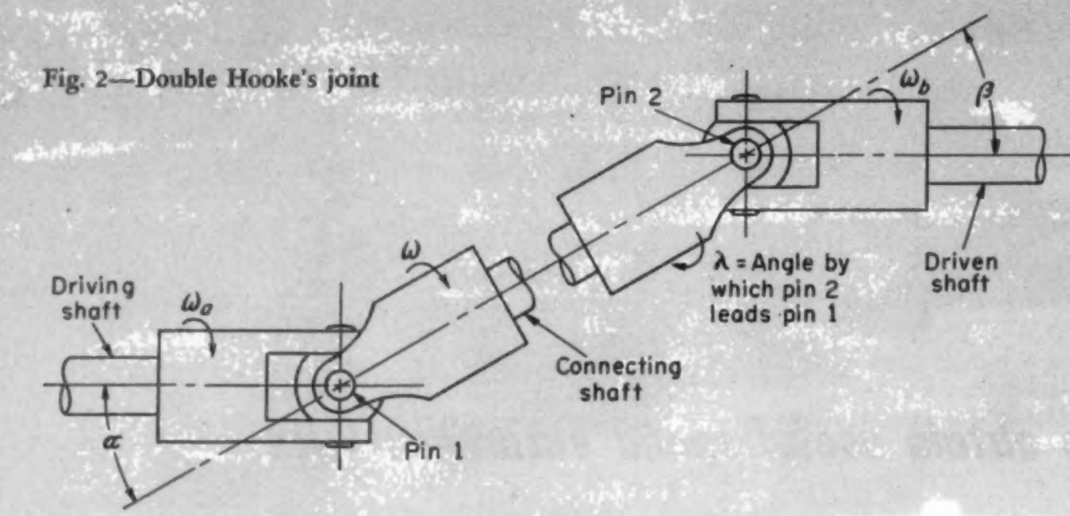
Sometimes the instantaneous position of the driven shaft must be known. Let θ_b represent the angular position of the driven shaft, measured from the zero position shown in *Fig.* 1. Then

$$\tan \theta_b = \sec \alpha \tan \theta_a \quad \text{(2)}$$

Double universal joints are often used to form a flexible connection between misaligned shafts. Most often they are mounted in such a way that the angular velocity variations are cancelled out. However, where velocity variations are desired, double joints offer a wider range of possibilities than does the single joint.

In determining the velocity characteristics of the double Hooke's joint, use is made of Equations 1 and 2. The instantaneous ratios of the two joints are multiplied together, just as the ratios of pairs of gears in a train. The only difficulty

Fig. 2—Double Hooke's joint



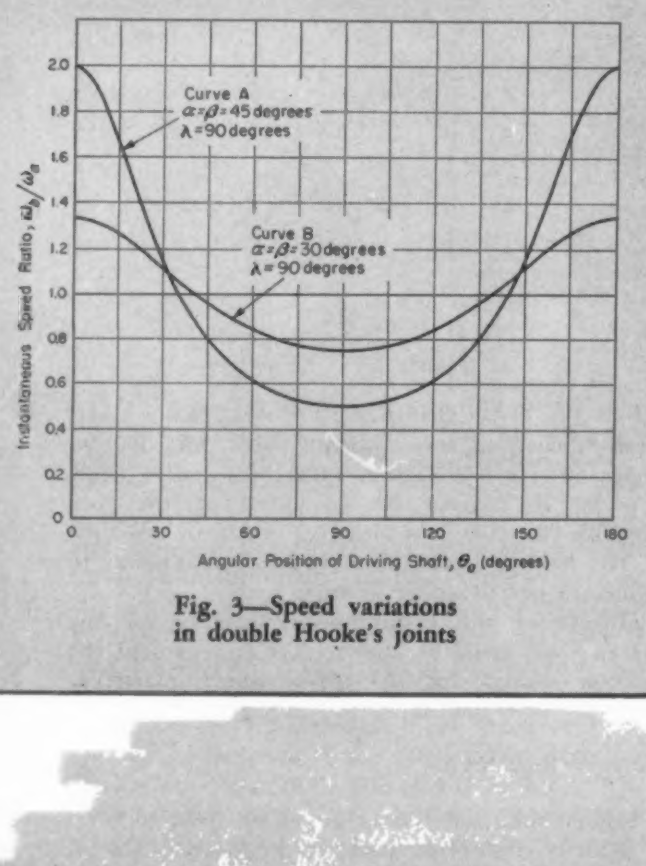


Fig. 3—Speed variations in double Hooke's joints

appears in determining the proper phase relationships of the various angles involved.

The general case of a double Hooke's joint is shown diagrammatically in *Fig.* 2. It is convenient to refer every possible setup to a diagram of this kind, where

α = True angle between the driving and connecting shafts

β = True angle between the connecting and driven shafts (not necessarily equal to α)

θ = Angular position of connecting shaft, zero

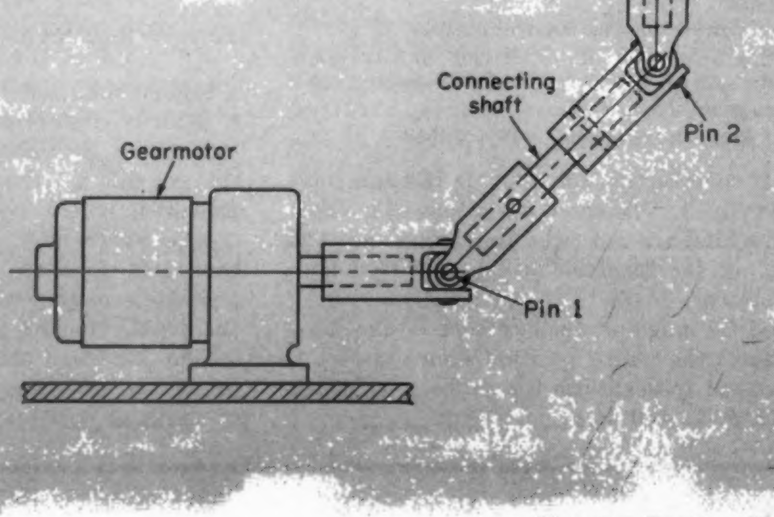


Fig. 4 — Mechanism for varying-speed crank drive

in the position shown and positive in the direction indicated by the arrow for ω

θ_a = Angular position of the driving shaft, measured from the zero position shown, positive in the direction indicated by the arrow for ω_a

θ_b = Angular position of driven shaft

λ = Angular displacement of pin 2 ahead of pin 1, zero in the position shown and positive sense as indicated by arrow

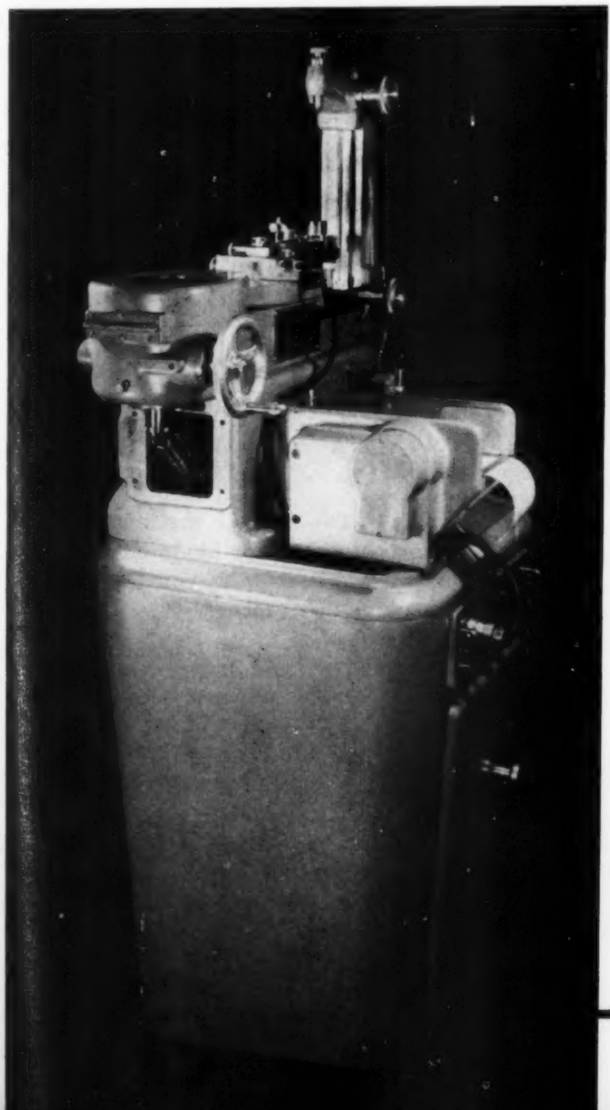
ω = Angular speed of connecting shaft

ω_a = Angular speed of driving shaft

ω_b = Angular speed of driven shaft

Fig. 2 is not a true picture of the most general case, but it is a simplified diagram which aids in visualizing any possible arrangement. The velocity characteristics are unchanged if the second joint, together with the driven shaft and the link pin 2, are rotated rigidly through any angle about the axis of the connecting shaft. Thus the planes of the true angles α and β do not need to be the same, and the driving and driven shaft axes may be intersecting or skew. However, all cases can be reduced to the coplanar case shown in *Fig.* 2, without changing their velocity characteristics, by means of the aforementioned rigid rotation about the connecting shaft. Thus the equations

Fig. 5 — Prototype of tooth-spacing comparator illustrating use of varying-speed drive



which follow will be based on the arrangement shown in *Fig.* 2:

$$\tan \theta = \tan \theta_a \sec \alpha \qquad (3)$$

$$\frac{\omega_b}{\omega_a} = \frac{(1 - \sin^2 \alpha \sin^2 \theta) \cos \beta}{[1 - \sin^2 \beta \sin^2 (\theta + \lambda)] \cos \alpha} \qquad (4)$$

$$\tan \theta_b = \tan (\theta + \lambda) \cos \beta \qquad (5)$$

As stated before, the usual applications of double Hooke's joints have an overall constant speed characteristic, that is, $\omega_b/\omega_a = 1$ for all values of θ_a. The constant speed condition can be seen from Equation 4; $\alpha = \beta$ and $\lambda = 0$. This condition exists when the driving and driven shafts are parallel and the two pins on the connecting shaft are parallel to one another, which is the usual recommended mounting for universal joints.

The condition $\alpha = \beta$ is, of course, always true when the driving and driven shafts are parallel. However, even skew and intersecting shafts can be mounted in such a way that the true angles are equal. Since this simplifies the computation, it is probably the best way to assemble the joints even when velocity variations are desired.

For the setup shown in *Fig.* 2, the maximum speed variation characteristics occur when pin 2 is assembled 90 degrees from pin 1, so that $\lambda = 90$ degrees in the equations.

A practical numerical example demonstrates these conclusions. Let $\alpha = \beta = 45$ degrees and $\lambda = 90$ degrees.

Substituting these conditions into Equations 3, 4 and 5 gives

$$\tan \theta = 1.4142 \tan \theta_a \qquad (3a)$$

$$\frac{\omega_b}{\omega_a} = \frac{1 - 0.5 \sin^2 \theta}{1 - 0.5 \cos^2 \theta} \qquad (4a)$$

$$\tan \theta_b = - \frac{0.70711}{\tan \theta} \qquad (5a)$$

When $\theta_a = 0$, $\theta = 0$, $\omega_b/\omega_a = 2$, and $\theta_b = 90$ degrees. This initial position for the driven shaft should be visualized with the aid of *Fig.* 2, by rotating the second joint through the pin displacement angle of 90 degrees, and noting that the position of the driven shaft must then be 90 degrees ahead of the position shown in the drawing.

When $\theta_a = 30$ degrees, $\tan \theta = 0.81649$, $\omega_b/\omega_a = 1.1429$, $\tan \theta_b = -0.86603$, and $\theta_b = 139.107$ degrees.

The computation can be repeated for other arbitrary values of θ_a. The results for this example are plotted as Curve A in *Fig.* 3. The total speed variation for a case where $\alpha = \beta = 30$ degrees and $\lambda = 90$ degrees is also shown as Curve B in *Fig.* 3.

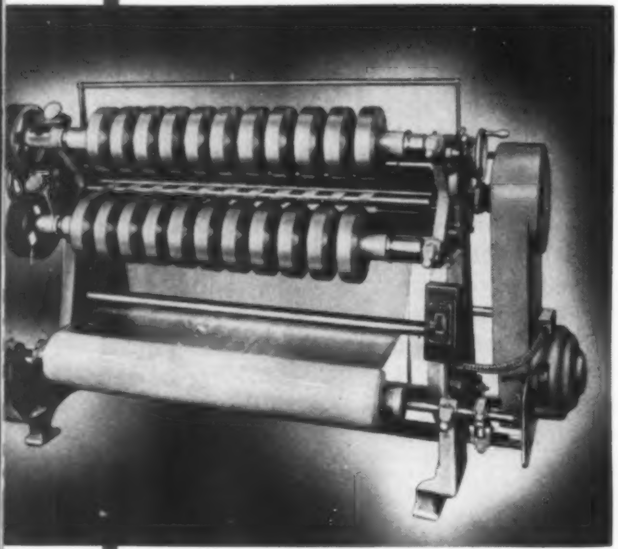
The mechanism shown in *Fig.* 4 has the speed

variation characteristics similar to Curve A of *Fig.* 3. Note that the driving and driven shafts are at right angles, the connecting shaft makes an angle of 45 degrees with each of them, and the pin displacement angle is 90 degrees. The output shaft drives a crank mechanism through a 2-to-1 speedup gear, so that the speed variation goes through only one cycle in one revolution of the crank. This arrangement was used successfully on an early model of the new Illinois Tool Works gear tooth spacing comparator, *Fig.* 5. Here the loads and speeds are low enough to permit using standard joints at the extreme angularities. The machine measures the spacing of gear teeth by stroking through successive teeth, and the speed variation reduces the idle time in each stroke.

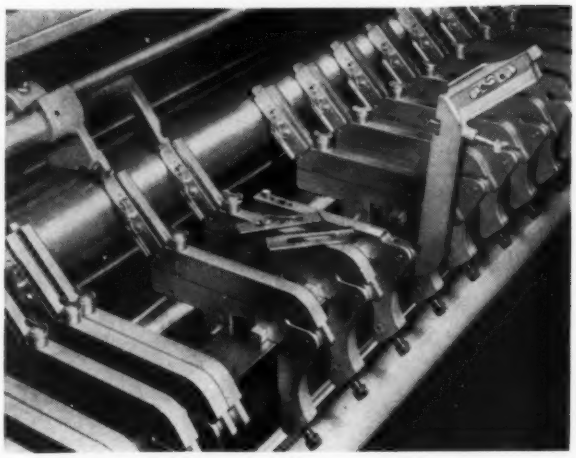
Where loads and speeds are high or the driven member has high inertia, estimates of the maximum loads must be made and compared with manufacturers' recommendations for the joints. Accelerations can be obtained mathematically by differentiating the formulas, or graphically by measuring the slopes of curves such as the ones shown in *Fig.* 3.

CONTEMPORARY DESIGN

Die Castings Hold Razor Blades in Slitter



AN ASSEMBLY of two zinc die castings holds razor blades in a slitter and rewinder developed by Charles Beck Machine Corp. Designed to cut roll cellophane, acetate and plastics, the slitter has blades whose spacing is set to roll width.



Each holder consists of two zinc die castings hinged at one end so that the razor blade can be changed. Elements for assembly of the razor blade in the holder are cast in.

Only opening in the parts which is not cored in the die casting operation is the hole for the set screw (arrow) which, because of its angle in relation to the die parting, is drilled and tapped. Simple trimming operations to remove metal flash and broaching are the only other operations required.

AUTOMATIC MACHINE CONTROL

How electrical signals proportional to machine operating conditions may be obtained and used for control or as indications of performance

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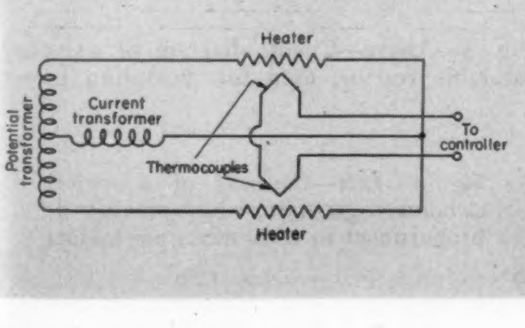
AUTOMATIC control of a machine depends upon precise measurement of one or more of its process or performance variables. These variables include such quantities as temperature, pressure and flow, speed, load, torque, tool wear, and faulty performance. Temperature, pressure and flow can usually be measured and controlled directly; the others are more difficult to keep under surveillance. In these latter cases, an indirect method must be applied.

One indirect method is the measurement of power consumption of a machine which, when judiciously interpreted, can be related to machine performance. When converted into a usable dc voltage, it may be employed as a means of control. Torque and speed, also functions of machine performance, may likewise be converted into measurable electric currents. Devices for converting these variables into electrical quantities are called transducers.

A transducer which will successfully transform mechanical or electrical power into a measurable electrical quantity, should have these characteristics:

1. Low power consumption—it must not consume an appreciable amount of the power supplied to the equipment with which it is to be used.
2. Reproducibility and accuracy—it must develop a reproducible and accurate relationship between its output and the actual power measured.
3. Extraneous effects—accuracy must not be affected by variables such as power factor and current level.
4. Sensitivity—it must be sensitive enough to detect power changes of the magnitude required

Fig. 1—Single-element thermal converter circuit, which transforms ac power into proportional dc current



to control the power within the limits set by the designer.

Power Measurement. The most adaptable transducers for power measurement are the thermal converter, solenoid-plunger ammeter, precision shunt and the saturable reactor.

THERMAL CONVERTER. From the machine designer's point of view, one of the most useful transducers is the thermal converter. This device converts ac electrical power into a proportionate dc voltage, which makes it useful as a means for measuring and controlling the power to mixers, grinders, and similar machines. Its principal advantages are accuracy and ability to convert power directly with a sensitivity well within the requirements of most equipment. The thermal converter is extremely fast acting. For example, it will produce a change in dc output equal to 99 per cent of the actual change in power in less than one second. Of particular importance to the designer is its reputation for requiring little or no maintenance and having extremely long life.

The thermal converter comprises a transformer for voltage input, a transformer for current input, and a network of heaters and thermocouples, *Fig.* 1. Although heat generated in a resistance is proportional to the square of the current flowing in it, the output of this device is linear for power measurement. The circuit provides for cancellation of all squared terms, leaving only a term proportional to the product of the "in phase" voltage and current.

A basic single-element thermal converter circuit is shown in *Fig.* 1. Polyphase models are also available. Output of the converter is linear at 0.1 millivolt dc per watt input, which can be maintained for direct or reverse energy flow to within ± 1 per cent. Maximum input is 500 watts. In terms of voltage or current, the input limitations are about 115 volts or 5 amperes. If the current

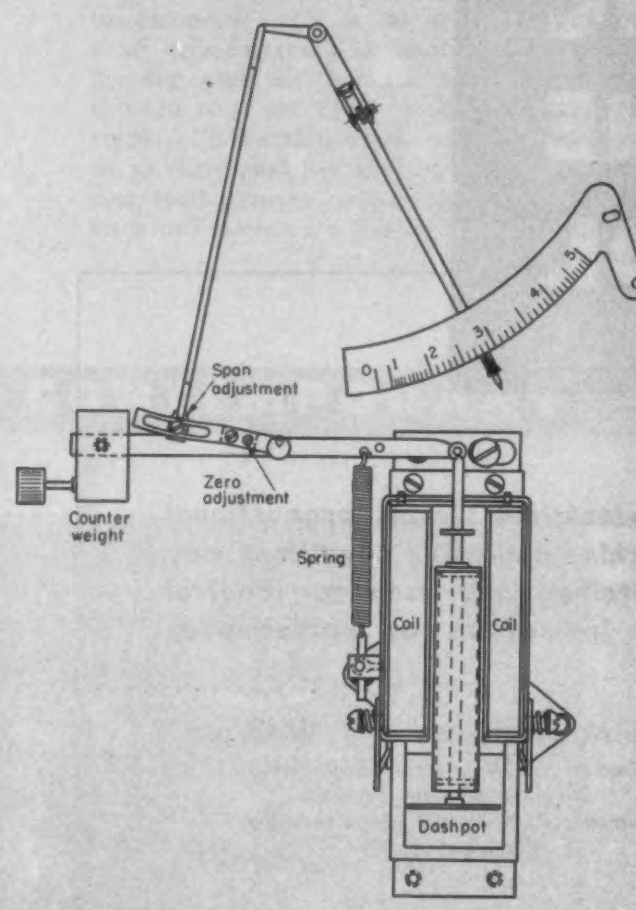
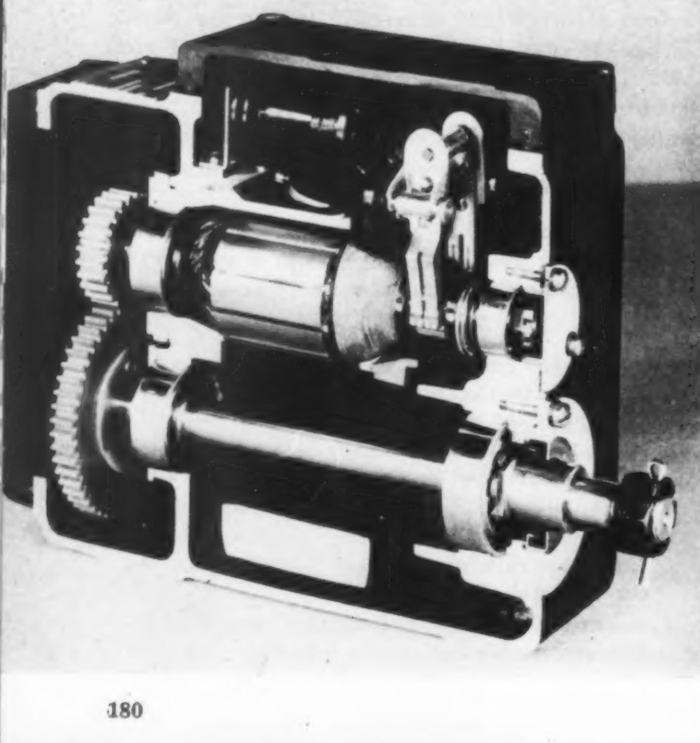


Fig. 2—Solenoid-plunger ammeter giving direct indications proportional to ac power. To insure proportionality only about 40 per cent of solenoid stroke is used



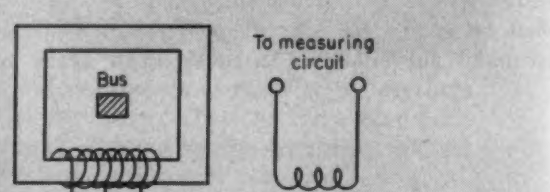


Fig. 3—Above—Circuit diagram of a typical saturable reactor, used for measuring power

Fig. 4—Left—Cutaway of a typical tachometer-generator which provides dc proportional to revolutions per minute

or voltage exceeds the maximum input limit, as it frequently does in many applications, suitable transformers must be used to reduce the input to the required value. Desirable limits are:

Voltage Input	113 to 123 volts ac
Current Input	0 to 5 amperes
Frequency	56 to 64 cycles per second
Power Factor	0.75 or higher

Speed of response of these thermal converters is less than one second. For applications where rapid or transient fluctuations in power are present, an indicating or recording controller with a slower speed of response can be used. This will prevent excessive wear on the power-regulating mechanism. It has been found that for most applications the maximum full-scale speed of response of the instrument need not exceed 4½ seconds. In the large majority of installations, 12 seconds is acceptable.

In addition to the basic type of thermal converter which transforms ac power to dc voltage, variations of this transducer are possible which convert either a-c current or (ac) voltage to a measurable dc voltage. When conditions permit, more economical design can be achieved with a modified unit. Essentially these comprise only one half of the basic thermal converter used to convert power. Characteristics and speed of response of both the current and voltage-converting units are the same as those of the basic thermal converter. All three may be used with identical instrumentation for measurement and control.

SOLENOID-PLUNGER AMMETER. When economy of design precludes the use of a current or voltage thermal converter, a recording and controlling ammeter can be used provided the applied power is a reproducible function of the supply current. The most common industrial controlling ammeter available is the solenoid-plunger type, currently finding wide application in cement processing on pulverizing machinery. This device can be calibrated to within ±1 per cent of full scale for measurements up to 5 amperes. Current in excess of five amperes is applied through a current transformer. The solenoid-plunger ammeter is particularly useful as a high-limit cutoff device for preventing damage to expensive equipment by shutting off the applied power when it exceeds a preselected, manually adjustable value.

As shown in *Fig.* 2, this transducer consists of an armature suspended in a coil from a beam balance and spring arrangement. This is linked mechanically to the pointer of the meter.

Measured current, applied to the coil directly or through a current trasformer, produces a magnetomotive force which positions the armature. Except for about 40 per cent of armature travel, the curve of current versus armature position is nonlinear. This difficulty is overcome by arranging the linkage so that full-scale pointer travel occurs only over the linear portion of armature travel. A dashpot is added at the bottom of the armature to remove line frequency oscillations and random variations in the measured current. For applications requiring high-limit cutoff, an auxiliary pressure-measuring device or an electric contact control unit is incorporated in this type of ammeter.

PRECISION SHUNT. Current input to a machine may also be measured with the aid of a precision resistor inserted into the line in parallel with an ammeter. Although this device is highly accurate and easy to maintain it has two disadvantages in power applications. First, if it cannot be inserted in the electrical ground lead, its location requires the measuring circuit of the controller to be oper-

Table 1—Characteristics of Power Measurement Transducers

	Measured Variable	Accuracy	Use	Principal Advantage	Principal Disadvantage
			Ac Devices		
Thermal converter	Ac watts	Excellent	Accurate control and recording	Accurate measurement of watts	High cost
Inductance solenoid-plunger ammeter	Alternating current	Good	Control and recording	Convenient for pressure and flow applications	No significant disadvantage
			Dc Devices		
Precision shunt	Direct current	Excellent	Dc current measurement and control	Simple construction and installation	High operating potential size for large currents
Saturable reactor	Direct current	Good	Dc measurement and control 5000-100,000 amperes	Insulated from high voltage	Requires rectifiers in output

ated at a potential above ground. This is usually inconvenient and, with very high voltages, may be too dangerous. Second it is limited in high-current applications. The precision shunt is economically feasible up to about 5000 amperes, but above this its large size and cost make it impractical.

SATURABLE REACTOR. Although more expensive, the saturable reactor, *Fig.* 3, has an appreciably broader field of application.

In this device the current-carrying wire or bus is encircled by a piece of iron which serves as the core of a reactor. The dc current in the bus tends to saturate the flux capacity of the iron core, and any change in current results in a change in the impedance of the reactor. Thus, the iron core is the primary element of the system. Since it can be insulated from the power circuit, the measuring circuit can be operated at ground potential.

Torque Measurement. When the measurement of mechanical power is desired, the designer has a choice between direct and inferential methods of obtaining a measurable change in output for a corresponding change in applied torque. Of course direct measurement is by far the most desirable and convenient and should be considered during the initial design stage of the machine.

A direct-measuring torquemeter is highly accurate, independent of power factor and voltage changes, and is equally usable on either ac or dc equipment. A typical example, the Baldwin torquemeter, is a calibrated shaft containing a bonded strain-gage bridge. Torsional forces developed in the shaft stress the strain-gage elements. The resulting distortion causes a change in strain-gage resistance which is proportional to the applied torque. This change in resistance is transmitted to an indicating or recording controller.

Torquemeters have been successfully used for torque measurements on aircraft, automotive, marine and stationary engines, and to make studies of tapping and drilling torques. These applications indicate that such a device can be a valuable tool in design improvement. Because of the difficulty of inserting torquemeters into the drive system after the system has been installed, it is important to provide for them in original design.

One practical alternative to a torquemeter is a device for measurement based upon the proportionality which exists between current input and torque in a drive motor. Here again either the current-converting thermal converter previously mentioned, or the solenoid-plunger ammeter can be used as a transducer on ac equipment. The thermal converter, however, cannot be used to obtain such measurements on dc equipment. For these, the best alternative is either a solenoid-plunger ammeter equipped with a dc coil or a saturable reactor in conjunction with a rectifier system.

Speed Measurement. Another transducer readily adaptable for speed measurement and the control of machinery is the tachometer-generator. This device produces a dc output proportional to the speed of the rotating shaft to which it is coupled. *Fig.* 4 shows the principal features of a typical unit including the drive shaft, the external terminals, and the conduit plug that is used when the generator is subjected to dampness or corrosive atmospheres. The unit can be mounted with the shaft in a vertical or horizontal position.

Output of the tachometer may be used to oper-

Fig. 5—Typical instrumentation for automatic blow tank consistency control in pulp mills. Power consumed by agitator is converted to a dc indication which in turn controls automatically the flow of dilution liquor

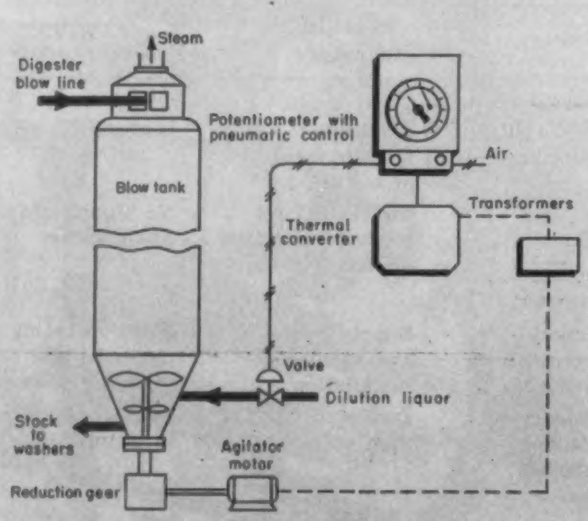
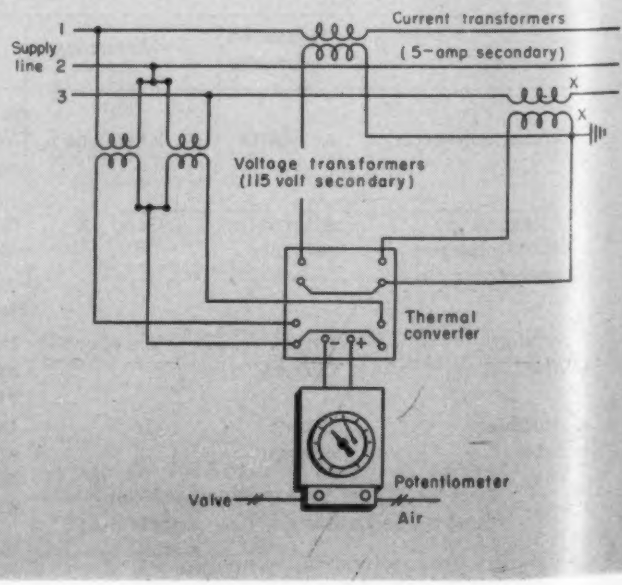


Fig. 6—Detail of the thermal circuit used with the consistency control illustrated in *Fig.* 5



ate an indicating or recording controller. Through the use of gear boxes, much flexibility of measurement can be achieved. By means of an integrator, such quantities as the length of the product can also be controlled.

Automatic Control. After selection of the proper transducer, the second link in the control system must be chosen. This second device must control the final driven element with the electrical quantity representing the machine process.

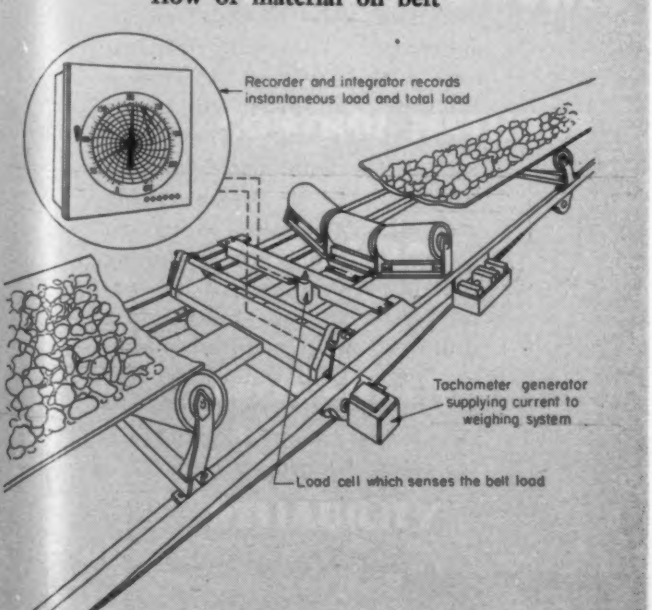
Indicating or recording controllers are used to apply the corrective action to the machine drive. They may be pneumatically operated to position valves, dampers, louvers or similar devices. Electrically operated units set relay contacts to provide automatic control.

TYPICAL APPLICATIONS. Consider the design of a control system for continuously measuring, recording, and controlling the consistency of paper stock by automatically regulating the flow of black liquor used in its dilution. A simplified sketch of the control loop is shown in *Fig.* 5.

This represents a conventional blow-tank process used in alkaline pulp mills in which the consistency of the paper stock must be maintained at a fixed value. Since consistency cannot be measured directly, inferential means must be used. For this system, a thermal converter was selected which translates flunctuations in agitator motor load into a dc voltage directly proportional to the load. The voltage is conducted to the input terminals of the recording and controlling instrument.

When the consistency of the stock in the blow tank changes, the load on the agitator and consequently the power consumed by its drive motor also change. Suitable voltage and current transformers connected as shown in *Fig.* 6 conduct this variation in power demand to the thermal converter, which evaluates it as a change in heat energy. The integrally mounted thermocouple in the thermal converter detects the resulting change in temperature and conducts it to the recording and controlling instrument as a dc error signal which actuates the servo system to reposition the pen.

Fig. 7—Belt weighing system using a tachometer-generator and a strain-gage load-cell transducer. Speed and load signals combine to show rate of flow of material on belt



Difference between pen position and the desired control point represents a deviation from the required consistency. The movement of the pen is transmitted by means of a differential linkage to a pneumatic control unit which translates the change into a corresponding change in output air pressure from a pneumatic transmitter. The output of the transmitter goes to a diaphragm valve which is located in the dilution liquor flow line. Thus, valve position is continuously changed in the proper direction to restore the consistency to the desired value.

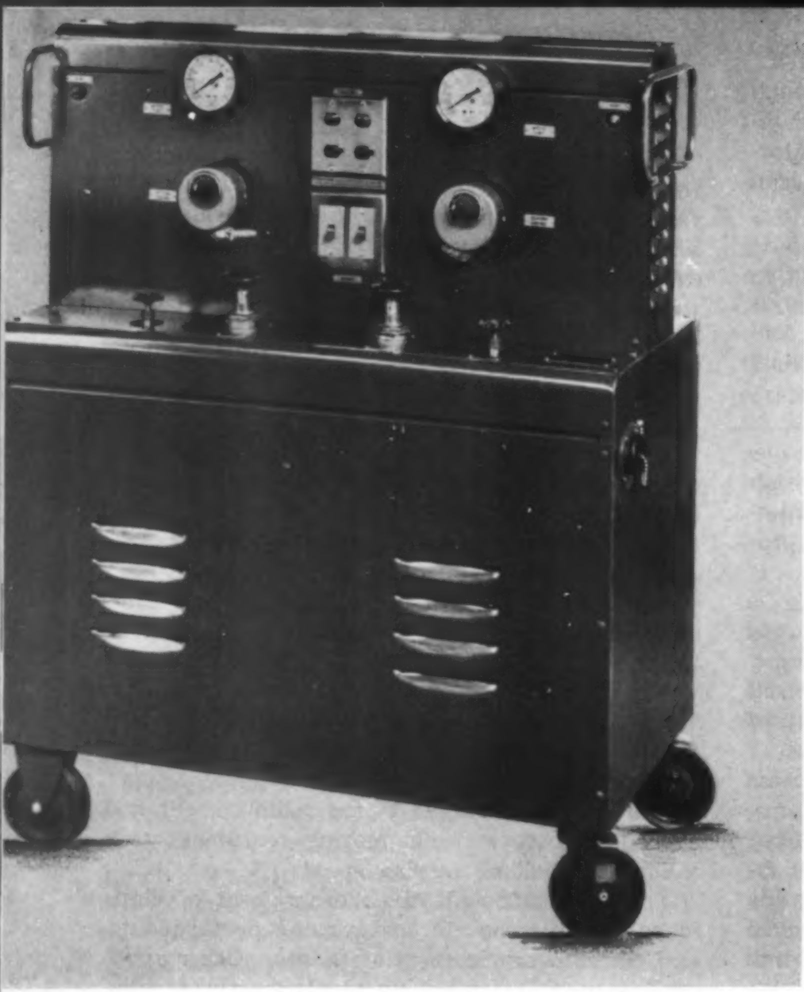
Still another example is the measurement and control of loose material moving continuously on a conveyor belt of varying speed.

Applications include the measurement of chips in paper mills, fuel in coal-burning power plants, and ore recovery in smelting plants. Other applications exist in cement machinery, mines, fertilizing plants, feed mills, chemical equipment and food processing machinery.

Blending of materials such as the minute addition of vitamins to cereals, oil to coal for dust control, or liquids to solids carried by the conveyor, can be accomplished by pneumatically positioning a ratio or remote set point positioning mechanism on a secondary flow controller on the liquid line.

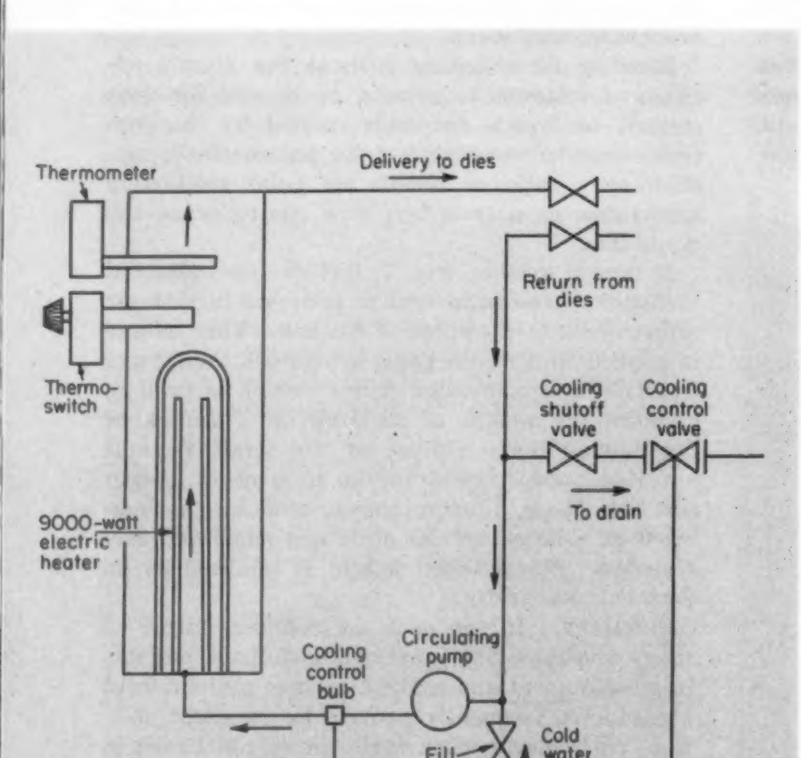
A typical system, *Fig.* 7, includes an industrial tachometer-generator which produces a voltage proportional to the speed of the belt. This voltage is applied to a strain gage, a load cell transducer sensitive to compression forces, which is used to measure the weight of material on a section of the moving belt. Output of the strain gage is a voltage proportional to the product of weight and belt speed. Instantaneous flow rate is indicated on a large circular scale and simultaneously recorded. Accumulated weight is totalized by an electronic integrator.

SUMMARY. In the past the complex nature of many machines has presented a difficult problem in measurement and control. Power measurement transducers frequently provide an excellent solution, particularly when their use is considered in the initial design stages of the machine. The designer, who is most familiar with the characteristics of the process, can best determine where to apply the device for most efficient operation and effective control. The needs of the application, the degree of accuracy required, and economic factors will govern the selection of the transducer as well as the instrumentation required.



Automatic Machine Controls Plastics Mold Temperature

ONE widely used method of controlling mold temperature in plastics injection presses is by manual control of cooling-water flow through channels in the mold. With manual control, wide variations in both temperature and pressure of city water necessitate frequent adjustment of the valve; usually adjustment is not made until the need is manifested by an increase in rejects. An automatic mold temperature control unit, developed by Sterling Inc., provides automatic control of this mold cooling water to maintain correct mold temperature at all times. Total water volume required by the automatic unit is low, because cooling water is recirculated through the machine by an integral circulating pump.



A 9000-watt immersion heater is controlled by a Fenwal immersion type Thermoswitch. Switching point of this thermostat may be set at any temperature between 60 and 210 F by a calibrated knob on the front panel of the unit. Thermometers on the front panel indicate temperature of water being pumped to the dies. A cooling control bulb operates a cooling control valve to bypass hot water returning from the dies to a drain when temperature rises too high. Cold water from the supply line then feeds into the circulating pump to replace water being drained.

CONTEMPORARY DESIGN

DESIGN MANUAL

ADJUSTABLE-SPEED ELECTRIC-MOTOR DRIVES

By Robert C. Rodgers
Assistant Editor, Machine Design

SPEED RANGE

TORQUE AND POWER

CONTROL METHODS

REGULATION

EFFICIENCY

RELIABILITY

COST

WHAT THE DESIGNER SHOULD KNOW ABOUT

ADJUSTABLE-

Adjustable speed is a common requirement in design, but a requirement having many facets. To aid selection and design in this important area, *Machine Design* will present comprehensive design guides on each of the types of adjustable-speed drive systems—electric motors, slip-coupling methods, mechanical drives, and fluid-power (hydraulic and pneumatic) drives.

This first article deals exclusively with electric motors. It provides practical information for the designer on all electrical methods of stepped or stepless motor speed adjustment:

1. Changing characteristics of electric power input—frequency, phase, voltage—to the drive motor by converters, rectifiers, or motor-generator sets.

2. Changing impedance—resistance and/or reactance—in various sections of the motor circuit.

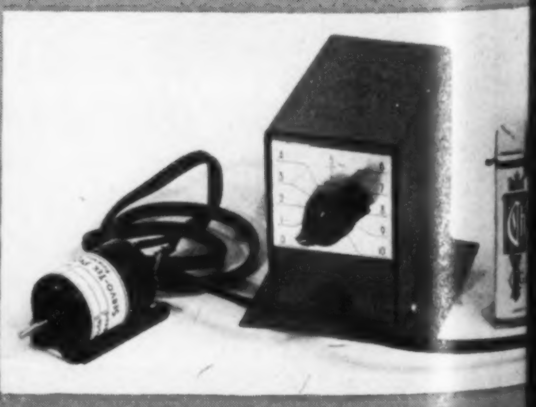
3. Changing motor design by reconnecting motor windings or by shifting brushes.

Articles on mechanical and fluid-power adjustable-speed systems as well as on other electrical methods will be presented in future months.

A NATURAL and rising demand for features of speed adjustment in electric motors is creating an almost unlimited array of new and improved units and systems. Today they range in size from "fleapower" permanent-magnet electric motors with electronic speed adjustment, *Fig.* 1, to huge adjustable-speed wind-tunnel drives, *Fig.* 2. Another striking example is a recent installation of a twin-motor drive for a blooming mill. It develops 10,000 hp and is able to reverse from 40 rpm in one direction to 40 rpm in the opposite direction in one second.

Appliances incorporate small *built - in*

Fig. 1 — A 1/300-hp permanent-magnet motor and its one-tube electronic adjustable-speed control box



Photo, courtesy Servospeed, Div. of Electro Devices Inc.

-SPEED ELECTRIC-MOTOR DRIVES

two-speed universal motors, *Fig.* 3. Large 3000 to 6000-hp diesel-electric, gas-turbine electric, or ignitron-rectifier electric locomotives may also have *built-in* electric motor drives, *Fig.* 4.

Many ac and dc electric motors may be controlled with a simple adjustable rheostat inserted in series with the motor input circuit, *Fig.* 5, or in the secondary circuit of some induction motors. Regulation and efficiency are not the most favorable but initial control equipment cost is low.

Where more rigid regulation, speed, size and automatic-control requirements are encountered, dc motors and more elaborate

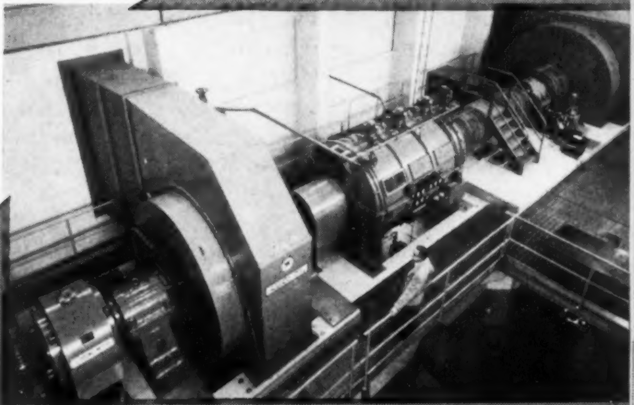


Fig. 2 — A Westinghouse 18,000-hp synchronous-motor and Dynamatic eddy-current coupling adjustable-speed drive for a transonic wind tunnel at Boeing Airplane Co.

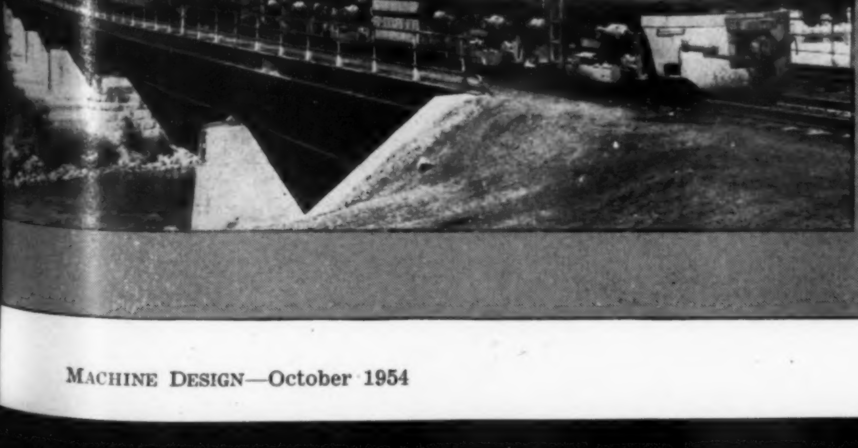


Fig. 3—Above — Small two-speed universal motor for a portable food mixer

Photo, courtesy General Electric Co.

Fig. 4—Left—A modern electric locomotive with built-in adjustable-speed drives of several thousand horsepower

control and conversion equipment is often necessary. These applications may call for separate power conversion units and control equipment, *Fig.* 6, which are often built into the machine at various points. Or "packaged" drives are often employed to convert ac to dc for adjusting speed of integral-horsepower dc motors, *Fig.* 7.

A single knob or lever may control speed and direction of rotation of literally dozens of motors, *Fig.* 8, or several motors in one machine may be individually controlled, *Fig.* 9.

In the broadest sense, an adjustable-speed drive means one that can be purposely adjusted from one speed to another. Although the term is frequently limited to "stepless" adjustable-speed drives, it is applied here to "stepped" types also. Any of the numerous systems that convert electrical energy to rotating mechanical power with a smooth speed adjustment (infinitesimally small steps) over a specified speed range is a stepless type. On the other hand, a *two-speed* squirrel-cage motor is an example of one kind of stepped adjustable-speed drive. In this article both stepless and stepped types will be discussed.

Basic Selection Factors: In the application of an adjustable-speed drive of any type, many practical aspects require study to justify the drive itself or the selection of a specific kind. Basic factors include drive power, speed range, speed and torque regulation, reliability, initial cost, operating cost, and expected maintenance expense.

Power, speed and torque factors depend largely on load characteristics and duty cycle. In adjustable-speed applications load requirements are commonly classified in one of three categories: (1) Constant power, variable torque, (2) constant torque, variable power and (3) variable torque, variable power. According to the load, a drive may fall into combinations of these classifications at different parts of a speed range.

Duty cycle must be evaluated to determine if loads are steady, intermittent, or varying. Often, inertia of rotating parts should be carefully analyzed. Of course, since the drive is to be adjustable in speed, the maximum and minimum speed must be determined. Along with speed, the degree of regulation actually necessary must be established; this factor is important because regulation within unnecessarily close limits is wasted money and may not be required or even wanted in many applications. Wide speed ranges and low values of regulation increase both equipment size and expense.

Increased reliability may or may not increase initial and operating costs because it is largely dependent on the type of drive system selected.

Maximum drive horsepower may be limited by the capacity of the main power source or the feeder lines. For example, a domestic 110-volt line and panel cannot supply the electrical power available through an industrial main power panel.

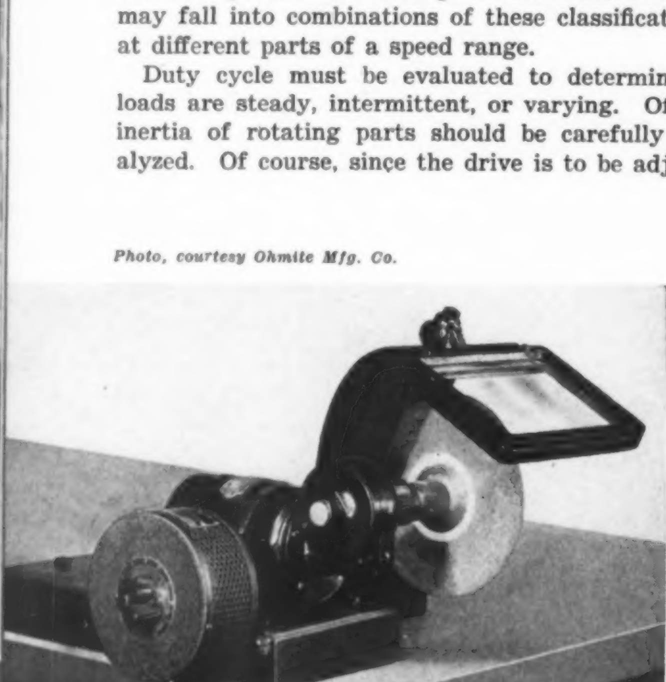
Economic justification of an adjustable-speed drive of any kind requires cost comparisons with other means of obtaining the same result. For example, gears or pulleys can be changed to obtain different speeds. But frequent speed changes by such methods would raise both labor costs and idle machine time, and perhaps adversely affect other dependent facilities. Realistic analysis of these charges may frequently justify the higher first cost of control equipment.

Of course, adjustable speed is a must where automatic sequencing, synchronization and control are required. Other points to consider are simplicity

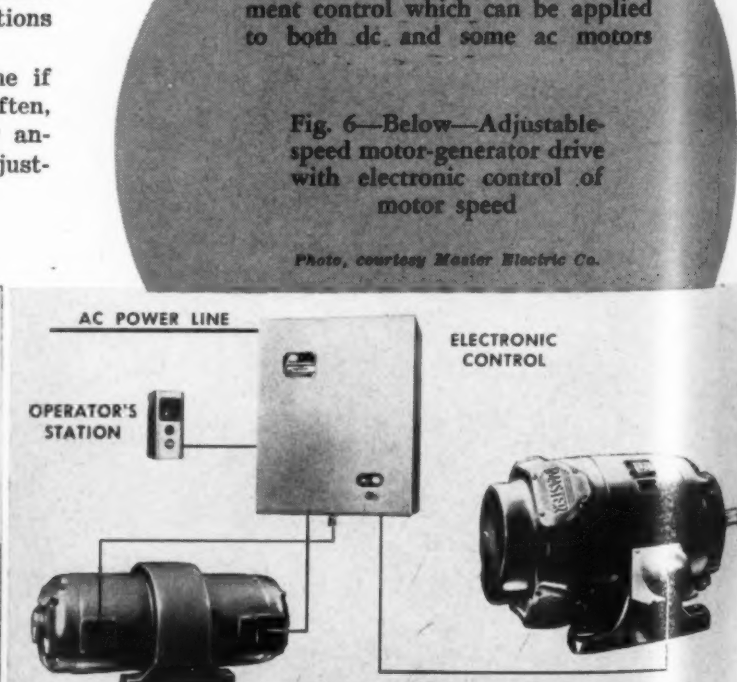
Fig. 5—Left—A specialty grinder with simple rheostat speed-adjustment control which can be applied to both dc and some ac motors

Fig. 6—Below—Adjustable-speed motor-generator drive with electronic control of motor speed

Photo, courtesy Ohmite Mfg. Co.



Photo, courtesy Master Electric Co.



and flexibility of control.

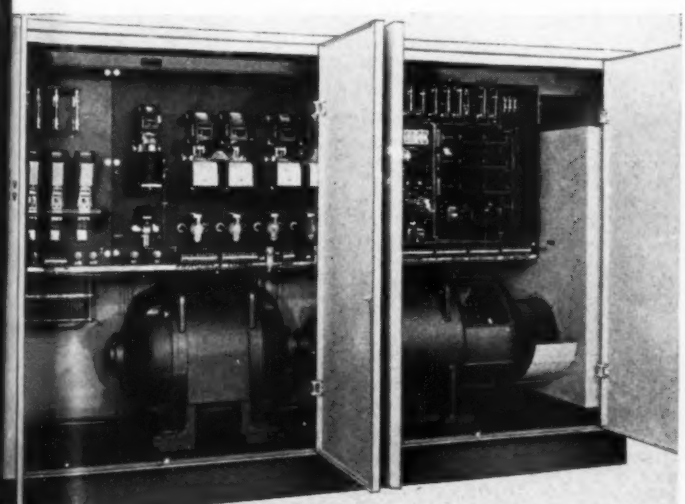
Size and weight of a machine is sometimes lower powered by an electric motor that is electrically adjustable in speed, if control equipment need not be placed on the machine itself. In design or selection of drives, environmental conditions often are particularly important. They include ambient air and machine temperatures and air circulation. Other factors are humidity, dust, dirt, lint, flying liquids, flying debris, corrosive atmospheres, vibration, shock, and hazardous locations.

Often, the task of picking the right drive is simplified if the influences of the foregoing factors are logically formulated into a tentative specification of minimum drive requirements. Then the matching of these requirements with the attributes of all types of adjustable speed drives will narrow the choice to the few best selections that are possible.

In the application of electric motors that are essentially constant in shaft output speed, the theory of electric motor operation is relatively unimportant to most machine designers. One can select and apply a motor to meet the specifications on the basis of data concerning electric power input, horsepower, speed, speed regulation, initial cost, etc.

However, when adjustable-speed electric motors are utilized, the electric power input and/or motor circuitry are usually being changed quite often. Therefore, familiarity is required with more than just the relationship of motor size to horsepower and whether the motor is connected to alternating current or direct current.

In the selection of adjustable-speed electric motors, understanding of basic factors which affect motor torque, speed and horsepower is a prerequisite. At the same time, inherent limitations with respect to motor acceleration, deceleration, reversing, and stopping should be understood. Also, the factors of motor circuit protection and operating



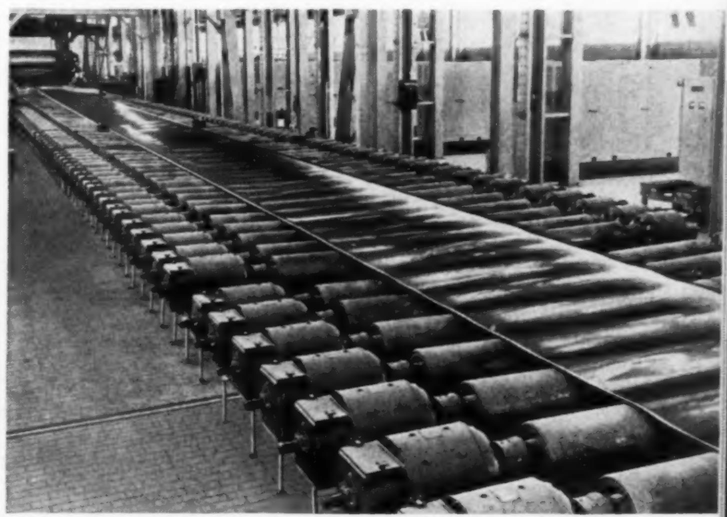


Fig. 7 — Above — "Packaged" adjustable speed motor-generator drive with magnetic-amplifier control
Photo, courtesy Allis-Chalmers Mfg. Co.

Fig. 8—Above right—A steel mill roll-out table with literally dozens of dc motors controlled by a single lever
Photo, courtesy Reliance Electric and Engineering Co.

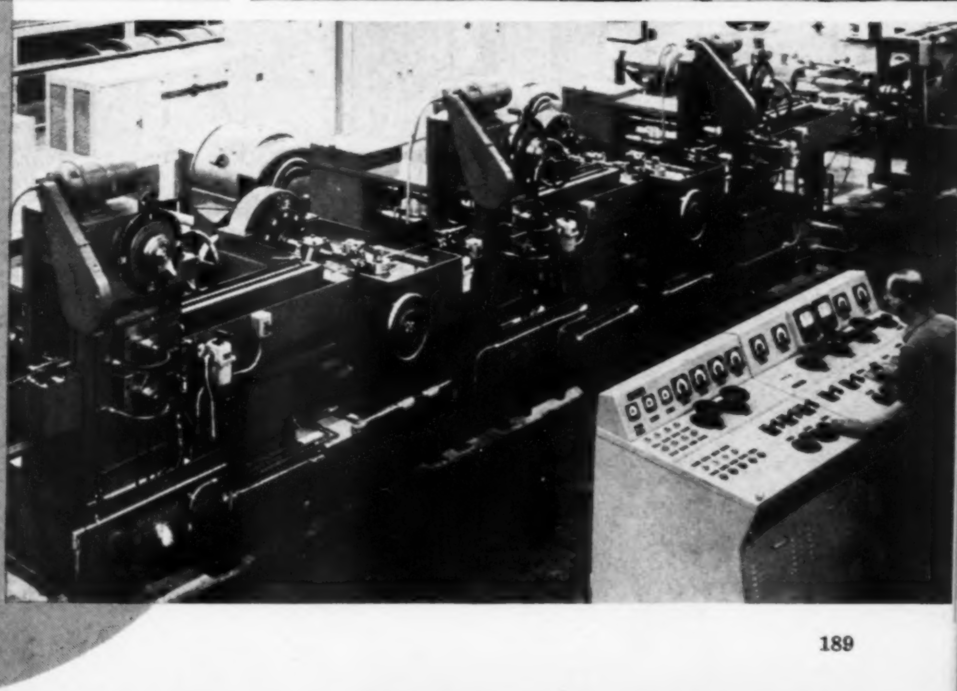


Fig. 9 — Right—Three-stand tandem wire flattening mill in which many motors can be individually controlled from a central control panel
Photo, courtesy General Electric Co.

limitations of motors from a heating standpoint are important. Although many of these facets must be considered with constant-speed motors, they are usually multiplied in importance with adjustable-speed motor applications.

Selection of the right motor for a specific adjustable-speed application is an important decision. In some applications, many different motors could be specified. Sometimes it may be difficult to choose the particular motor that is superior in performance and initial cost and also outstanding from an operating and maintenance standpoint, except through practical experience. However, familiarity with electric motor operation, characteristics, and limitations is also an aid in the evaluation of pertinent drive requirements of the machine itself.

Motors are available in many special shapes, output power ratings, voltage ratings, etc., but the designer is wise to select a motor that is commonly available, provided it meets design requirements. Such a motor is easy to obtain, for initial assembly or for replacement, and it will usually cost less. Both ac and dc motors are employed in adjustable-speed drives. The operating characteristics, application considerations and limitations, and commercially available types of both will be discussed in this article.

SPEED ADJUSTMENT OF DC MOTORS

Direct-current motors are widely used for applications in which control of speed or torque is a primary consideration. They are by far more commonly used in adjustable speed applications than ac motors—especially where wide speed ranges are required. Also in portable or mobile equipment dc motors are necessary because the power is frequently supplied from batteries. Factory trucks, *Fig.* 10, lift trucks, automotive equipment, portable recording instruments, etc., are typical applications where dc motors are used in great number. In industrial plants, special equipment is required to convert ac power to dc power to operate adjustable-speed dc motors; however, the higher initial investment is usually warranted by increased production or other benefits.

Photo courtesy Electric Specialty Co.

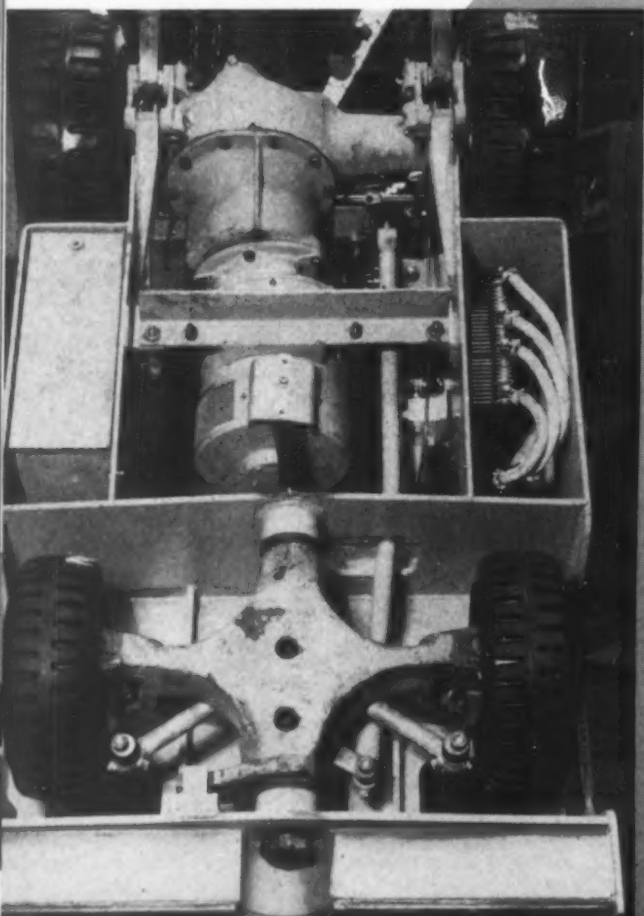
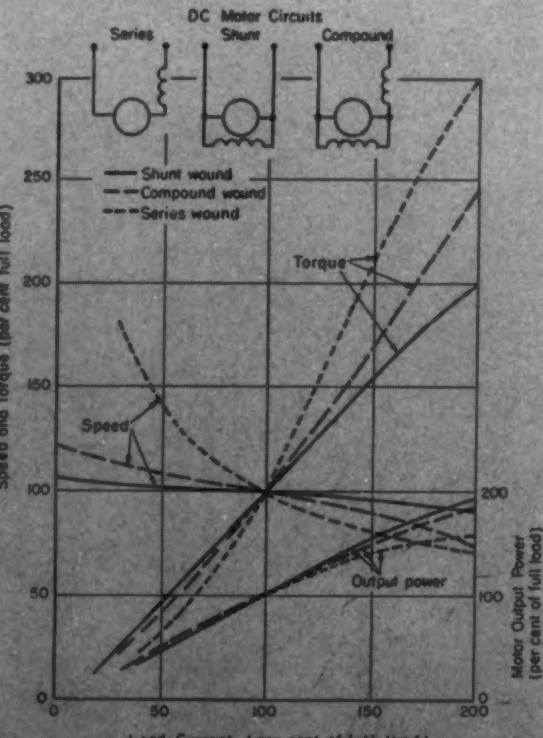


Fig. 10—Left—Yale and Towne truck with battery-powered dc-series motor. Four speeds are provided by drum controller and motor series resistors

Fig. 11—Speed, torque, and output power characteristics of typical series, shunt and compound dc motors



ADJUSTABLE-SPEED ELECTRIC-MOTOR DRIVES

Nomenclature

E = Line voltage, volts
E_b = Dc motor countervoltage, volts
E_g = Dc generator developed voltage, volts
E_e = Dc motor effective armature voltage, volts
E_f = Dc voltage across dc machine field, volts
E_t = Motor terminal voltage, volts
E_{tL} = Voltage across dc motor armature with load, volts
E_{tNL} = Voltage across dc motor armature with no load, volts
f = Ac frequency, cycles per second
I = Line current, amperes
I_a = Dc motor armature current, amperes
I_{aL} = Dc motor armature current with load, amperes
I_{aNL} = Dc motor armature current with no load, amperes
I_f = Dc current through dc machine field, amperes
K = Ac and dc motor or generator constants (Subscripts m and g denote motor or generator when used in same equation; otherwise, subscripts 1, 2, etc., denote different physical values for *motor* constants)
P = Motor output power, hp
P_i = Motor input electrical power, hp
p = Number of poles
R_a = Resistance of dc motor armature, ohms
$R_{a,\,gen}$ = Dc generator armature resistance, ohms
R_f = Resistance of dc motor field, ohms
$R_{f,\,ser}$ = Resistance of series field of dc series-shunt motors, ohms
$R_{f,\,sh}$ = Resistance of shunt field of dc series-shunt motor, ohms
R_{line} = Resistance of lines connecting generator and motor armatures, ohms
R_v = Variable or adjustable resistance, ohms
r_g = Radius of gyration of rotating part, ft
S = Motor rotational speed, rpm
S_{FL} = Motor full-load speed, rpm
S_{NL} = Motor no-load speed, rpm
S_a = Actual ac motor speed, rpm
S_s = Synchronous ac motor speed, rpm
s = Slip in motor speed from synchronous, per cent
T = Motor torque, lb-ft
t = Approximate time required to accelerate or decelerate a load from one given speed to another given speed, seconds
W = Weight of rotating part, lb
Wr_g^2 = Inertia of rotating part, lb-ft²
η = Electrical-mechanical conversion efficiency of drive, per cent
ρ = Speed regulation, per cent
ϕ_f = Total effective field flux, lines per sq in.
ΔS = Difference between two given speeds, rpm

Table 1—Basic Formulas

Direct-Current Motors*

$$T = K_1 I_a \phi_f \qquad (1)$$

$$S = K_2 \frac{E_t - I_a R_a}{\phi_f} \qquad (2)$$

$$I_a = \frac{E_t - E_b}{R_a} = \frac{E_e}{R_a} \qquad (3)$$

$$E_b = E_t - I_a R_a = \frac{\phi_f S}{K_2} \qquad (4)$$

$$E_e = E_t - E_b = E_t - \frac{\phi_f S}{K_2} \qquad (5)$$

$$\phi_f = K_3{}^x I_f \qquad (6)$$

$$I_f = \frac{E_f}{R_f} \qquad (7)$$

Alternating-Current Motors†

$$T = K_4 E_t^2 \qquad (8)$$

$$S = \frac{120 f}{p} \left(\frac{100 - s}{100} \right) \qquad (9)$$

$$s = \frac{S_s - S_a}{S_s} \qquad (10)$$

General Characteristics

$$T = \frac{5250 P}{S} \qquad (11)$$

$$S = \frac{5250 P}{T} \qquad (12)$$

$$P = P_i \eta = \frac{T S}{5250} \qquad (13)$$

$$P_i = \frac{E I}{746} \qquad (14)$$

$$\eta = \frac{P}{P_i} (100) \qquad (15)$$

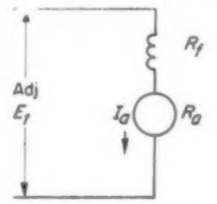
$$\rho = \frac{S_{NL} - S_{FL}}{S_{FL}} (100) \qquad (16)$$

*Also applicable to ac series motors and universal motors.
†Except for ac series motors and universal motors.

TABLE 2—SPEED ADJUSTMENT OF

Series Motors

(a) Adjustable Voltage



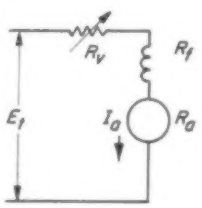
Decrease in E_t decreases T, S and P.

$$T = K_5 I_a^2$$

$$S = K_2 \frac{E_t - I_a (R_f + R_a)}{\phi_f}$$

$$I_a = \frac{E_t - E_b}{R_f + R_a}$$

(b) Series Resistance



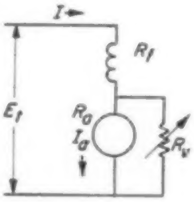
Formula for T same as in method (*a*). Usually $R_{v\,max} < R_f + R_a$. Increase in R_v decreases T, S and P.

$$S = K_2 \frac{E_t - I_a (R_v + R_f + R_a)}{\phi_f}$$

$$I_a = \frac{E_t - E_b}{R_v + R_f + R_a}$$

$$R_v = \frac{E_t - E_b}{I_a} - R_a - R_f$$

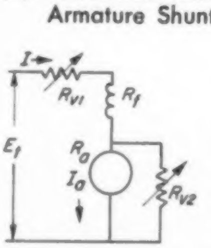
(c) Armature Shunt Resistance



Decrease in R_v decreases S, tends to maintain T, but may overheat field.

$$S = K_2 \frac{E_t - I R_f - I_a R_a}{\phi_f}$$

(d) Series Resistance and Armature Shunt

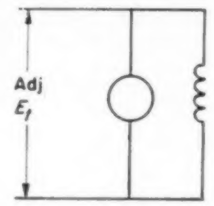


Increase in R_{v1} decreases T, S and P. Decrease in R_{v2} decreases S, tends to maintain T, but may overheat field.

$$S = K_2 \frac{E_t - I (R_{v1} + R_f) - I_a R_a}{\phi_f}$$

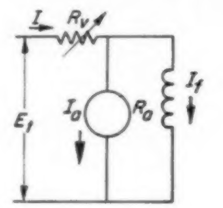
Shunt Motors

(e) Adjustable Voltage



Formulas for T and S same as in *Table* 1. Decrease in E_t decreases T, S and P.

(f) Motor Series Resistance



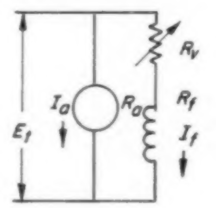
Formulas for T same as in *Table* 1. Increase in R_v decreases T, S and P.

$$S = K_2 \frac{E_t - I R_v - I_a R_a}{\phi_f}$$

$$I_a = \frac{E_t - R_v I_f - E_b}{R_a + R_v} = I - I_f$$

$$R_v = \frac{E_t - E_b - I_a R_a}{I_f + I_a}$$

(g) Field Resistance

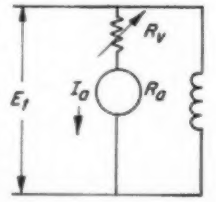


Formulas for T and S same as in *Table* 1. Increase in R_v increases S, decreases T, and P remains about constant.

$$I_f = \frac{E_t}{R_v + R_f}$$

$$R_v = \frac{E_t}{I_f} - R_f$$

(h) Series Armature Resistance



Formulas for T same as *Table* 1. Increase in R_v decreases S, but T and P are higher than in method (*f*).

$$S = K_2 \frac{E_t - I_a (R_v + R_a)}{\phi_f}$$

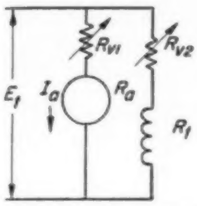
$$I_a = \frac{E_t - E_b}{R_v + R_a}$$

$$R_v = \frac{E_t - E_b}{I_a} - R_a$$

SELF-EXCITED DIRECT-CURRENT MOTORS

Shunt Motors (cont.)

(i) Field Resistance and Series Armature Resistance



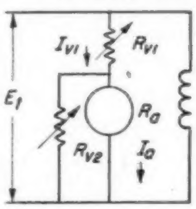
Formulas for T same as in *Table* 1. Increase in R_{v1} decreases S. Increase in R_{v2} increases S.

$$S = K_2 \frac{E_t - I_a (R_{v1} + R_a)}{\phi_f}$$

$$I_a = \frac{E_t - E_b}{R_{v1} + R_a}$$

$$R_{v1} = \frac{E_t - E_b}{I_a} - R_a$$

(j) Series and Shunt Armature Resistance



Formulas for T same as in *Table* 1. Increase in R_{v1} or decrease in R_{v2} decreases S and T.

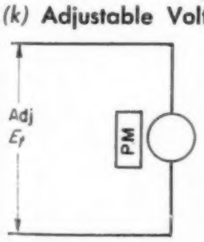
$$S = K_2 \frac{E_t - I_{v1} R_{v1} - I_a R_a}{\phi_f}$$

$$I_a = \frac{E_t - I_{v1} R_{v1} - E_b}{R_a}$$

$$R_{v1} = \frac{E_t - E_b - I_a R_a}{I_{v1}}$$

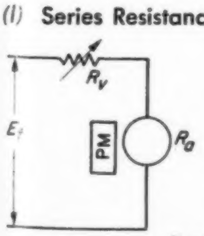
Permanent-Magnet Motors

(k) Adjustable Voltage



Formulas for T and S same as in *Table* 1. ϕ_f is not adjustable. Decrease in E_t decreases T, S and P.

(l) Series Resistance



Formulas for T same as in *Table* 1. ϕ_f is not adjustable. Increase in R_v decreases T, S and P.

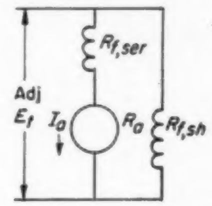
$$S = K_2 \frac{E_t - I_a (R_v + R_a)}{\phi_f}$$

$$I_a = \frac{E_t - E_b}{R_v + R_a}$$

$$R_v = \frac{E_t - E_b}{I_a} - R_a$$

Compound Motors

(m) Adjustable Voltage



Decrease in E_t decreases T, S and P.

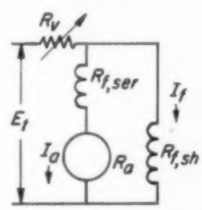
$$T = K_1 I_a (\phi_{f,\,ser} \pm \phi_{f,\,sh})$$

$$S = K_2 \frac{E_t - I_a (R_{f,\,ser} + R_a)}{\phi_{f,\,ser} \pm \phi_{f,\,sh}}$$

$$I_a = \frac{E_t - E_b}{R_{f,\,ser} + R_a}$$

$$E_b = E_t - I_a (R_{f,\,ser} + R_a)$$

(n) Motor Series Resistance



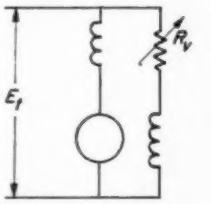
Formulas for T same as in method (m). Increase in R_v decreases T, S and P.

$$S = K_2 \frac{E_t - R_v (I_f + I_a) - I_a (R_{f,\,ser} + R_a)}{\phi_{f,\,ser} \pm \phi_{f,\,sh}}$$

$$I_a = \frac{E_t - E_b - I_{f,\,sh} R_v}{R_v + R_{f,\,ser} + R_a}$$

$$E_b = E_t - I_{f,\,sh} R_v - I_a (R_v + R_{f,\,ser} + R_a)$$

(o) Shunt Field Resistance



Formulas for T and S same as in method (m). Effect of R_v adjustment depends on whether motor is connected short or long shunt and cumulative or differential wound.

Practically all combinations of speed adjustment methods applied to shunt and series motors could be applied to compound motors. However, control becomes cumbersome and performance is difficult to predict.

Table 3—Standard Motor Service Factors

Output Power (hp)	AC Motors	DC Motors
1/20, 1/12, 1/8	1.4	...
1/6, 1/4, 1/3	1.35	...
1/2, 3/4	1.25*	...
1	1.25*	1.15
1-1/2, 2	1.20*	1.15
3 and larger	1.15*	1.15

For general purpose and continuous-duty motors having a rated temperature rise of 40 C. From NEMA Standards.

*For polyphase squirrel-cage integral-horsepower motors, these service factors apply only to Designs, A, B, C and F motors.

Table 4—Standard Power-Speed Ratings

Power (hp)	Approximate Full Load Speed (rpm)
1/20, 1/12, 1/8	
1/6, 1/4, 1/3	3450, 1725, 1140, 850
1/2	3450, 1725, 1140
3/4	3450, 1725
1	3450

For dc fractional hp constant-speed motors rated at 32, 115 and 230 v. From NEMA Standards.

Table 5—Speed-Regulation Limits of Fractional Horsepower Motors

Motor Output Power* (hp)	Speed (rpm)	Maximum Speed Regulation (per cent) Shunt Wound	Compound Wound
1/20 to 1/8	1725	20	30
1/20 to 1/8	1140	25	35
1/6 to 1/3	1725	15	25
1/6 to 1/3	1140	20	30
1/2 to 3/4	1725	12	22
1/2	1140	15	25

For standard direct-current, constant-speed continuous-duty motors. Based on full-load to no-load hot. From NEMA Standards.

*Horsepower size listings are inclusive.

Table 6—Speed-Regulation Limits of Integral Horsepower Motors

Motor Type	Motor Output Power (hp)	Speed Regulation (per cent)
Shunt-wound or stabilized shunt-wound, constant-speed, continuous-duty motors	5 and less	12
	Greater than 5	10
Compound-wound, general purpose, constant-speed, continuous-duty motors	1 up	25
Shunt-wound or stabilized shunt-wound, adjustable-speed, varying-duty motors	1½ and less	25
	2 to 5 inclusive	22
	Greater than 5	15

For standard dc motors. Based on full-load to no-load hot. From NEMA Standards.

For the three basic types of direct-current motors—series, shunt and compound—typical speed, torque and power characteristics are shown in *Fig.* 11. The compound motor can be designed to have practically any torque, speed and power characteristics between limits represented by the series and shunt motors.

Many factors influence the selection of a dc motor. For convenience in reference, some of these factors are summarized in *Tables* 1 to 10. How they can be used in design studies will be apparent from the following discussion.

ELECTRICAL CHARACTERISTICS

Equations 1 and 2 in *Table* 1 clearly show which electrical factors determine torque and speed of dc motors. Also included in *Table* 1 are the formulas for armature current, countervoltage, effective voltage, field flux, and field current in dc motors in Equations 3, 4, 5, 6 and 7, respectively. Each of these factors either influences dc motor speed and torque or is affected by speed and torque.

Countervoltage: One major factor which determines armature current is countervoltage. It is a generated voltage opposite in polarity to the line voltage and is often referred to as counter emf or back emf. The exact amount of countervoltage depends on several factors including the total flux strength of each field pole, number of poles, armature reaction, speed of armature rotation, and number of conductors on the armature. Actually, once a motor is built, countervoltage is mainly dependent only on field flux density and motor speed, *Table* 1, Equation 4.

Armature Current: Equation 3 in *Table* 1 shows that armature current is a function of effective voltage, the countervoltage subtracted from the terminal voltage, divided by armature resistance. Armature current can also be thought of as the algebraic sum of two currents which are trying to flow in opposite directions in the armature. Thus, armature current is quite high when a motor is first energized. The only factor limiting current flow is the ohmic resistance of the armature windings and brushes as countervoltage is zero until the armature begins to turn. Because of this high starting current, direct-current motors above 2 or 3 hp are usually started on reduced voltage starters, such as a face-plate controller, to prevent damage to the motor.

Motor Torque: Armature windings and brushes of a dc motor are so arranged that when energized with current the armature becomes, in effect, a strong electromagnet. The armature electromagnet "poles" are offset enough from the motor field

poles by position of the brushes on the commutator to cause maximum attraction or force between pole field and armature field and thus maximum turning torque. Motor torque is dependent on pole flux density, number of effective armature conductors, effective length of conductors, armature diameter, armature current, etc. However, once a motor is built the only factors which can be changed or adjusted to any extent to control torque are field flux strength and armature current as shown in *Table* 1, Equation 1. It should be noted from this equation that torque is independent of speed.

In the shunt motor, if field flux is held constant and starting current through the armature is three times normal full-load current, twisting effort or torque from the shaft of the motor will be in the order of 300 per cent rated full-load torque.

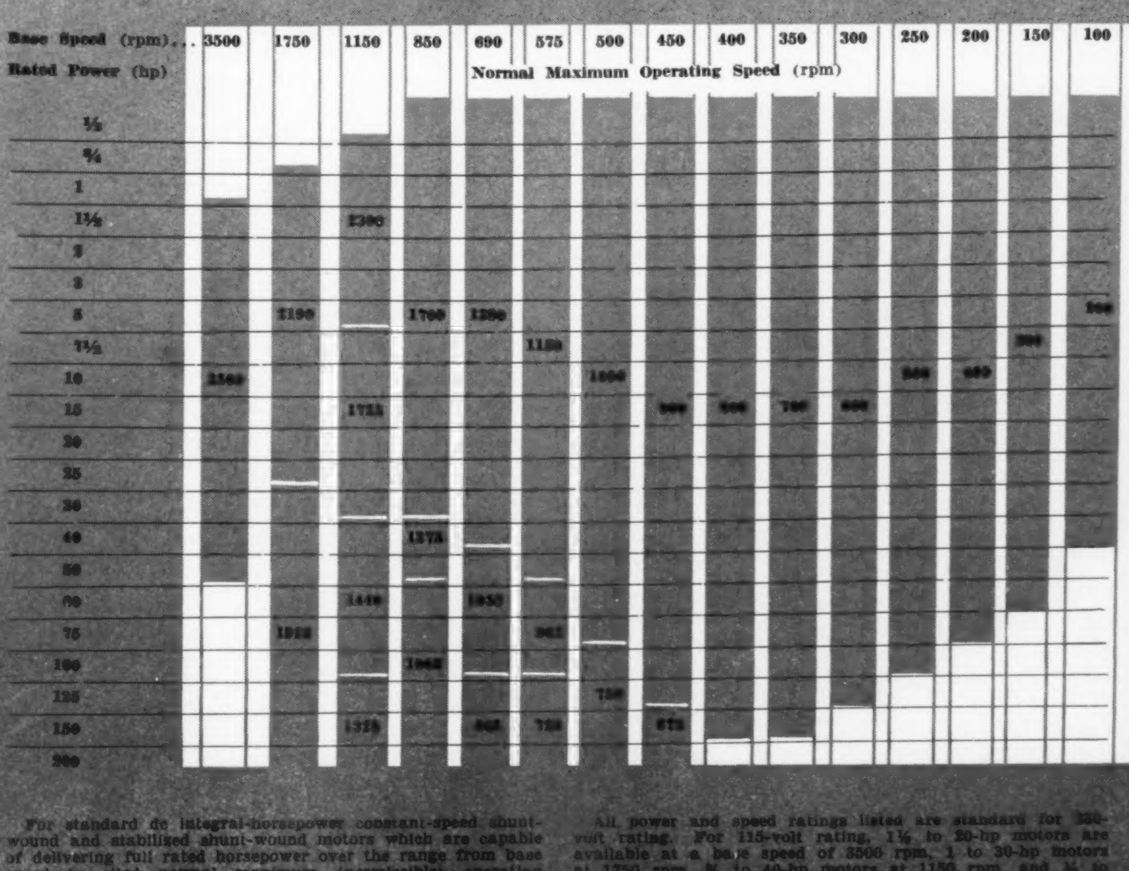
In the series motor of both the ac, dc, and universal types, field current and armature current are equal. Thus, if starting current is three times normal in the series motor, torque at starting will be about 900 per cent of normal.

For another comparison, assume that a series motor and a shunt motor are called upon to handle the same torque demand, such as 150 per cent of full-load torque. The series motor would require a little over 120 per cent of normal full-load current.

Speed of series motors varies more than that of shunt or compound motors for comparable load changes. It will be shown later how series motors are operated as separately excited shunt motors with electronic type speed controllers and have excellent operating characteristics.

Motor Speed: In the dc motor, speed may be changed over quite a range without appreciably reducing motor efficiency. This is one of the outstanding features of the dc motor for adjustable-speed applications. Operating speed of a dc motor is controlled by the armature terminal voltage, armature resistance, and field flux density. When more load is applied to the motor shaft, the motor naturally tends to slow down slightly (assuming

Table 7—Speeds Obtainable with Field-Weakening of Standard Constant-Speed Motors



For standard dc integral-horsepower constant-speed shunt-wound and stabilized shunt-wound motors which are capable of delivering full rated horsepower over the range from base speed to cited normal maximum (permissible) operating speed.

All power and speed ratings listed are standard for 230-volt rating. For 115-volt rating, 1½ to 20-hp motors are available at a base speed of 3500 rpm, 1 to 30-hp motors at 1750 rpm, ¾ to 40-hp motors at 1150 rpm, and ½ to 40 hp at 850 rpm and lower speed. From NEMA Standards.

Table 8—Speed Ratings and Ranges of Standard Adjustable-Speed Motors

Base Speed, (rpm)			1150	850	690	575	500	450	400	350	300	250
Rated Power (hp)			Normal Maximum Operating Speed (rpm)									
Continuous	One Hour	Tapered										
Rated Speed Range = 3 to 1												
½	¾	½—¾										
¾	1	¾—1	3450									
1	1½	1—1½		2550								
1½	2	1½—2			2070							
2	3	2—3										
3	5	3—5										
5	7½	5—7½				1725						
7½	10	7½—10					1500					
10	15	10—15										
15	20	15—20						1350				
20	25	20—25							1200			
25	30	25—30								1050		
30	40	30—40									900	
40	50	40—50										
50	60	50—60										
60	75	60—75										750
75	100	75—100										
100	125	100—125										
125	150	125—150										
150	200	150—200										
Rated Speed Range = 4 to 1												
½	¾	½—¾										
¾	1	¾—1										
1	1½	1—1½		3400								
1½	2	1½—2			2760							
2	3	2—3				2300						
3	5	3—5					2000					
5	7½	5—7½										
7½	10	7½—10										
10	15	10—15						1800				
15	20	15—20							1600			
20	25	20—25								1400		
25	30	25—30									1200	
30	40	30—40										
40	50	40—50										
50	60	50—60										
60	75	60—75										1000
75	100	75—100										
100	125	100—125										
125	150	125—150										
Rated Speed Range = 6 to 1												
½	¾	½—¾										
¾	1	¾—1				3450						
1	1½	1—1½					3000					
1½	2	1½—2						2700				
2	3	2—3							2400			
3	5	3—5										
5	7½	5—7½								2100		
7½	10	7½—10									1800	
10	15	10—15										

Standard motors are designed for 115-volt input for ½ to 20-hp sizes at all speeds, and for 230-volt input for all ratings listed. From NEMA Standards.

a constant field strength). This action reduces the counter emf and more armature current flows; thus motor torque increases. Since torque usually increases more than speed decreases, on a percentage basis, power of a motor usually increases under load.

It would appear that if voltage across the motor armature or motor field, or both, were adjustable and controllable, any speed, torque and horsepower could be obtained. Actually, of course, this is not so because of limitations of current capacity of armature and field windings, limits of commutation, centrifugal forces in the armature at high speeds, practical voltage limits of motor insulation, residual magnetism, and motor heating at low speeds and under overloaded conditions.

Table 9—Comparison of Direct-Current Motors

Shunt-Wound Constant-Speed	Shunt-Wound Adj.-Speed	Compound-Wound Constant-Speed	Series-Wound Varying-Speed
Speed Regulation*			
5 to 12 per cent without special control	10 to 20 per cent without special control	25 per cent with standard compounding. Depends on amount of series winding	Theoretically infinite
Speed Control Range			
From 2 per cent of base speed by voltage control to 200 per cent by field weakening	From 2 per cent of base speed by voltage control to 600 per cent by field weakening	Normally from base speed to 125 per cent base speed by field control	From zero to maximum speed depending on control and load
Starting Torque			
Good—125 to 200 per cent of full-load torque. Varies directly with armature supply voltage. Limited by starting resistance		Good — 130 to 260 per cent full-load torque. Limited by starting resistance	High — 300 to 350 per cent of full load torque. Varies as the square of current. Limited by commutation and heating
Maximum Momentary Operating Torque			
125 to 200 per cent. Limited by commutation and heating		130 to 260 per cent. Limited by commutation and heating	300 to 350 per cent. Limited by commutation and heating
Typical Applications			
Metal-working machines, wood-working machines, blowers, conveyors, centrifugal pumps, fans		Pulsating loads such as conveyors, plunger pumps, shears, crushers, hoists, elevators, bending rolls	Traction cars, cranes, hoists, car dumpers, elevators

*Special control methods provide speed regulation down to ½ per cent and less on any of these motors.

Speed of a dc motor is usually adjusted by controlling the voltage to, or the current flow in, the armature curcuit and/or field circuit. Resistors may be employed to control speed by various circuit arrangements. The effectiveness of various methods depends largely on the location of the control in the motor circuit and the type of motor. Tapped fields and split fields are sometimes employed, too. Adjustable-voltage power sources are also commonly used to control dc-motor speed.

Direct-current motors can also be adjusted in speed by shifting brushes. The more distant the brushes are positioned from the neutral commutating zone, the slower the motor speed because of less favorable commutation characteristics. This method is sometimes used with universal motors on machines such as food mixers. The mixer speed-adjustment knob moves the brushes with respect to the motor field poles. The method has at least two drawbacks: low motor power at low speeds, and heavy sparking which is injurious to the commutator.

In one early method of adjusting speed of dc motors a tapered armature was moved axially relative to tapered field poles. This displacement controlled the effectiveness of the field flux upon the armature flux or vice versa. Another version of this same approach was to move field poles me-

Table 10—Effects of Line-Voltage Variation on Direct-Current Motors

Voltage Variation (per cent)	Efficiency: Full Load	Efficiency: 75% Load	Efficiency: 50% Load	Full-Load Speed Change (per cent)	Full-Load Current Change (per cent)	Maximum Torque Change (per cent)	Overload Capacity Change (per cent)	Full-Load Temperature Rise: Main Field	Full-Load Temperature Rise: Comm., Field, Arm.
Standard Shunt Motors									
−10	Slightly lower	No change	Slightly higher	− 5	+11½	−16	−16	Higher	Higher
+10	Slightly higher	No change	Slightly lower	+ 5	− 8½	+15	+15	Higher	Lower
+20	Slightly higher	No change	Slightly lower	+10	−17	+30	+30	Higher	Lower
Standard Compound-Wound Motors									
−10	Slightly lower	No change	Slightly higher	− 6	+11½	−16	−16	Lower	Higher
+10	Slightly higher	No change	Slightly lower	+ 6	− 8½	+15	+15	Higher	Lower
+20	Slightly higher	No change	Slightly lower	+12	−17	+30	+30	Higher	Lower

Data, courtesy Allis Chalmers

chanically in or out radially to reduce flux effectiveness. In these methods of speed control, operation under load was somewhat poor and adjustments took time.

SERIES MOTORS

Speed of a series motor is quite sensitive to load; thus this motor is classified as a varying-speed motor. Reasons are apparent from the series-motor speed equations in *Table* 2. An increase in armature current reduces speed by (1) producing a larger $I_a R_a$ drop which reduces countervoltage and (2) increasing field flux. Therefore, speed can be reduced by any methods that lower counter emf, such as by a series resistor, *Fig*. 12, or increase field flux, such as with a shunted armature, *Fig*. 13.

If enough series resistance is added in the circuit of *Fig*. 12, motor speed can be decreased to zero, but 50 per cent speed reduction is usually considered the practical limit. With the series rheostat speed-adjustment method, initial control equipment cost is quite reasonable. Maintenance cost is low and reliability of operation is high, because there is practically no wear, if the design provides for dissipating heat generated in the resistors. Of course, overall efficiency is poor at reduced speeds, but this factor may be of small importance.

In the shunted armature method, *Table* 2(*c*), speed range is somewhat less, but speed is likely to be more stable, and starting torque is better because of a stronger field.

Another way to obtain series-motor speed control over a wide range and still retain reasonable stability at low speeds is to use a combination of resistors in series with the motor and a shunting resistor across the armature as shown in *Table* 2(*d*) and *Fig*. 13. Actual test with the load applied to the motor is required to determine necessary resistance values and wattage ratings of the resistors. Such testing is also needed to assure maximum speed stability. By adequate shunting, an essentially constant-speed characteristic is obtainable. Care must be taken to limit additional field current or time duty so that temperature rise of the field remains below a permissible limit. Because of the waste energy, the method is usually only recommended for intermittent duty or temporary slowdown.

To make a series motor run faster than normal for a given load, a variable resistance can be shunted across the field winding to reduce field current and, in turn, field flux. Then, adding a second resistor in series permits speed control below and above rated speed.

Any of these resistor speed-control methods could be applied to series motors in which the field circuit is split into two parts for reversible service, *Figs*. 14*a* and *b*. In another form of speed adjustment, which employs a split-field series motor and a special resistance controller, the two fields are connected in series with various values of resistance for low speeds and connected in parallel along with the same resistance value steps for higher speeds. A similar arrangement is utilized on elec-

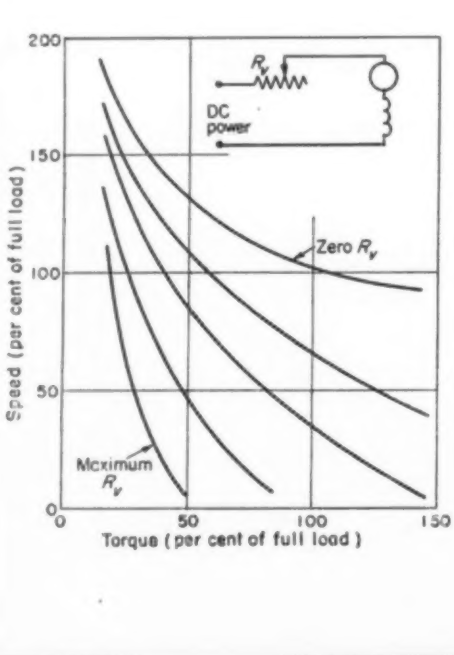
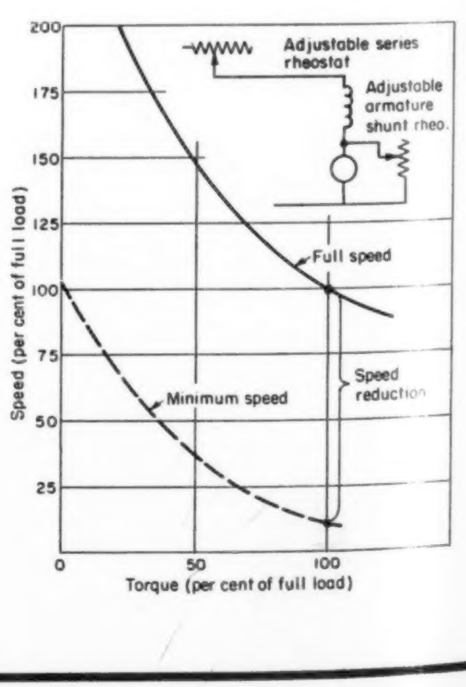


Fig. 12—Left—Characteristic speed-torque curves for a series motor with series resistance inserted

Fig. 13 — Right — Speed-torque characteristics of a dc series motor with both series resistance and armature shunt speed control employed



tric traction motor drives. Two separate series motors are connected in series at starting and low speeds. The resistance controller is constructed so that at about half-speed the motors are switched in parallel.

Series motors can be designed with tapped windings and, thus, speed steps are obtained with different taps and different effective ampere turns, *Fig.* 14*c*.

Stepped speeds can be obtained by switches, faceplate controllers, *Fig.* 15, drum controllers, *Fig.* 16, and master switches used with appropriate resistors. A list of typical values and types of adjustable resistors is shown in *Table* 11. Resistors and controllers must have higher wattage ratings if they are to be used for *both* starting and speed control.

SHUNT MOTORS

Speed of a shunt motor is far less sensitive to changes in load than the series motor. Assuming line voltage is held constant, the motor tends to slow down when more load is applied because armature current increases, which increases the $I_a R_a$ drop and lowers speed, *Table* 1, Equation 2. Actually the $I_a R_a$ drop is small relative to E_t, so that speed drop is small.

Another factor actually helps the shunt motor to maintain constant speed. An increase in armature current causes an increase in the armature magnetic field flux. This increased flux opposes and tends to cancel out a portion of pole field flux. This offsets some of the countervoltage decrease due to the increased $I_a R_a$ drop, and helps the shunt motor maintain more constant speed under load.

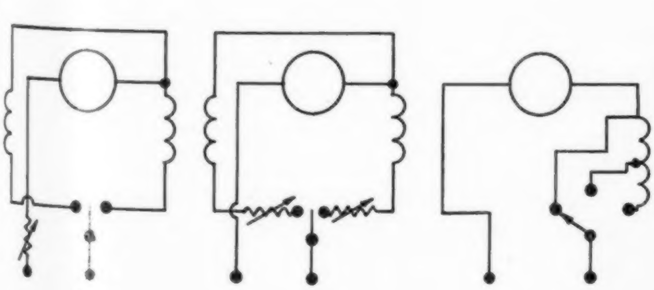
Because of these characteristics the shunt motor is often referred to as a constant-speed motor. Speed regulation is usually 12 per cent or less for motors in the 1 to 5-hp size range and 10 per cent for larger motors.

Another type of shunt machine is the stabilized shunt-wound motor. It has a field winding connected in series with the armature. This winding has the effect of modifying speed characteristics and at the same time improves motor torque, particularly in applications where load changes rapidly. Regulation of this motor is usually higher—15 to 25 per cent as shown in *Table* 6—because it is operating somewhat like a compound motor.

Methods of Increasing Speed: Speed of any shunt motor can be increased by any method that raises motor terminal voltage or lowers field strength. The latter method is often termed field weakening.

Speed on most standard direct-current constant-speed shunt motors listed in *Table* 7 may be about doubled in speed with series resistance inserted in the field circuit, *Fig.* 17. Some of the larger size motors are limited to lower speeds because they cannot be operated safely above the speeds listed in *Table* 7.

Fig. 14—Below—Resistance speed-control circuit for reversible split-winding series motor, *a*. Circuit *b* provides different preset speeds in each direction. Tapped windings provide stepped speeds in series type motors, *c*



(a) (b) (c)

Photo, courtesy Cutler-Hammer Inc.

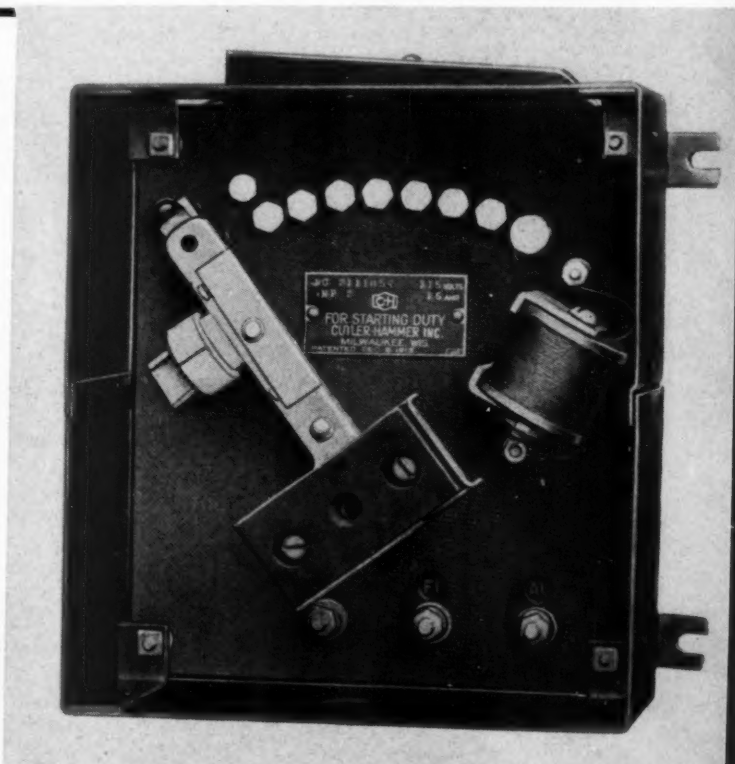


Fig. 15—Right—Interior of face-plate controller used for starting dc motors. Special controllers can be used for both starting service and resistance speed control of motor circuits

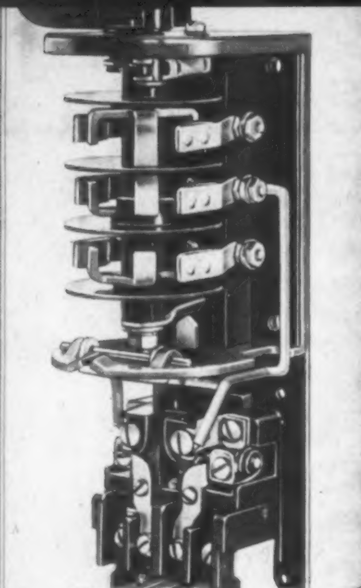


Fig. 16 — Left — Reversing drum switch for motor control with built-in overload protection rated at 5 hp, 550 v ac maximum

Photo, courtesy Furnas Electric Co.

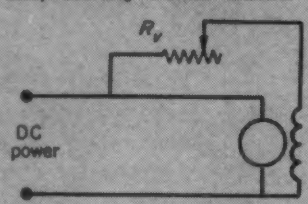
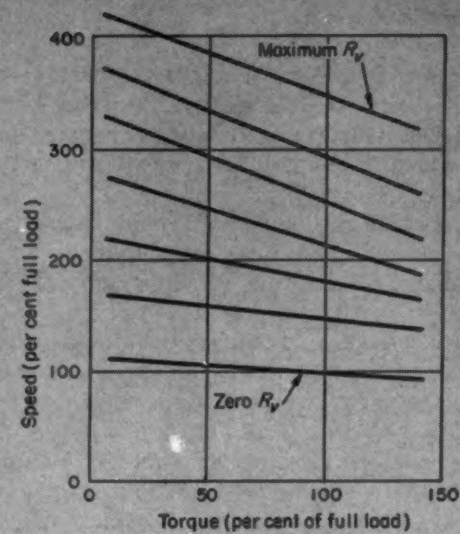


Fig. 17—Right—Field-weakening resistance speed control permitting speed increases as high as 6 times base speed with specially built dc-shunt motors



Even though speed can be doubled with field weakening, this practice is usually not considered too practical for speed increases more than 20 or 25 per cent above normal. If speeds much higher than rated are desired, so-called *adjustable-speed* shunt motors, *Table* 8, are more efficient. Such a motor is specially designed to operate safely at speeds greater than 200 per cent of normal. An adjustable-speed motor is defined as one whose speed can be adjusted as and when desired, but once a speed is selected, it remains practically unaffected by changes in load, much like the constant-speed shunt motor. The adjustable-speed motor is to be distinguished from the varying-speed motor which applies to a machine whose speed varies rather appreciably with load.

Adjustable-speed shunt motors are designed to permit greater field weakening so as to run at speeds as high as 8 times base speed. However, standard adjustable-speed motors are usually rated for 3 to 1, 4 to 1, or 6 to 1 service, *Table* 8. Limits within which speed can be changed by field control are set by both mechanical and electrical factors and the latter are often more significant. The

Table 11—Rheostat Types and Typical Applications

Type	Resistance Range (ohms)	Maximum Power Rating (watts)	Dimensions (in.)	Typical Adjustable-Speed Drive Applications
Faceplate	0.008 to 40	3000/cu ft (approx.)	Standard sizes range from 3 by 3 to 36 by 36	Dc motor starting and armature speed regulation; field control of large dc motors and alternators; voltage regulation and current control.
Plate				
Circular	0.5 to 5000	100 to 2000	4 to 18 diam	Field control of dc motors and generators; field control of synchronous motors.
Rectangular	0.5 to 2000	150 to 5000	4 by 6 to 15 by 24	
Plaque	1 to 1000	320	No standard sizes; typical unit 6 by 6	Armature speed control of fractional horsepower universal and dc motors; speed control of small electric fans.
Ring	0.5 to 10,000	25 to 1000 per ring	1⅛ to 12 diam	Field control of small ac and dc motors and generators; electronic rectifier control; magnetic amplifier control; toy train motor control.
Sliding contact	0.3 to 36,000	190 to 800	1⅝ by 8 to 2½ by 20	Manual voltage regulating, current control, voltage division, etc.; employed in some industrial drive installations for final set-up and operational adjustments where there will be little need for change after installation.

Data, courtesy Ward Leonard Electric Co.

higher the permissible speed range, the more expensive the motor becomes, of course, because the fields are especially wound and the motor frame is special.

As shown in *Fig.* 18, standard adjustable-speed shunt-wound motors are designed to carry either a constant-horsepower or tapered-horsepower load over the speed range. The constant-horsepower ratings are further subdivided into continuous operation with a permissible temperature rise of 40C and one-hour operation with a 50C temperature rise.

Rating a motor for continuous operation with a 40C temperature rise means that it will develop rated power from 150 per cent of base speed and up with only a 40C temperature rise *Fig.* 18*a*. However, from base to 150 per cent of base, the temperature rise may reach 50C. The 50C rise is usually considered safe. An adjustable-speed shunt motor rated for one hour operation with a 50C temperature rise can be rated at the next higher horsepower rating as shown in *Fig.* 18*b*. Actually the same motor can have a tapered horsepower rating, *Fig.* 18*c*, for continuous operation with a 40C temperature rise because of greater ventilation from the motor fan.

The important result of this rating system to the designer is the fact that, for example, a 10-hp adjustable-speed motor can do the job of a 15-hp motor on adjustable-speed applications if (1) operated most of the time at speeds higher than about three times base speed or (2) if used for only short periods of time.

Controlling speed of a shunt motor with an adjustable resistor in series with the shunt field gives a constant-horsepower variable-torque characteristic in which torque decreases with speed increases. Motor horsepower size that can be controlled is quite high since little current flows through the shunt field, relative to that in the armature. Speed regulation is poor at high speeds; for example, it is about 25 per cent at maximum speed on a 4 to 1 speed-range drive.

Fig. 18—Three basic methods of rating a 10-hp shunt motor in field-weakening speed control: (*a*) 10-hp continuous operation with permissible 40C temperature rise; (*b*) 15-hp one-hour continuous operation, 50C temperature rise; and (*c*) tapered horsepower rating, continuous operation, 40C temperature rise

Photo, courtesy Louis Allis Co.

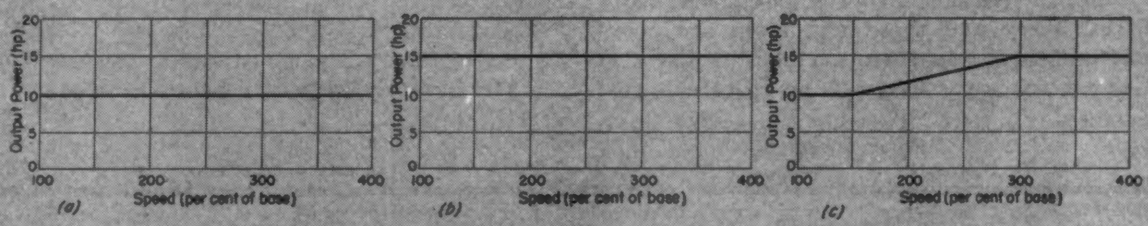


Fig. 19—Below—Motor speed versus field current by field-weakening speed control

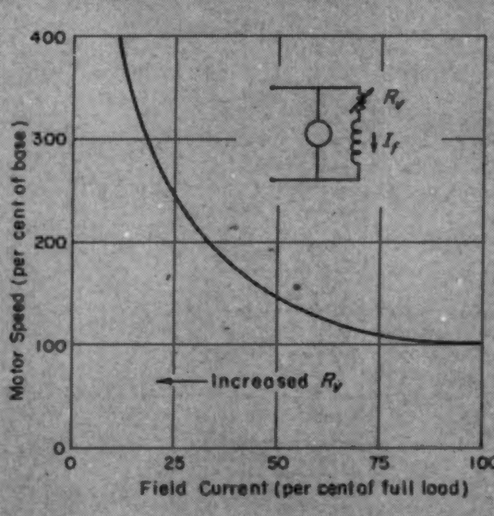
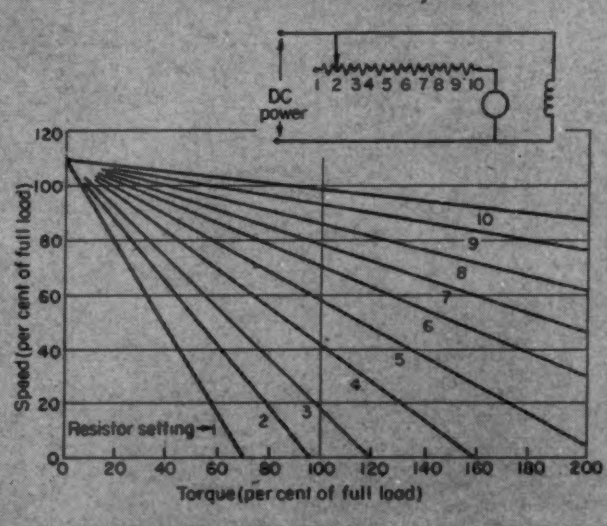


Fig. 20—Below—Speed-torque curves of a typical shunt motor controlled by armature circuit resistance adjustments



Calculating Field Resistance: Motor speed varies in direct proportion to field flux as shown in *Table* 1, Equation 2. However, field flux does not vary in direct proportion to field current and thus motor speed does not either, *Fig.* 19. The exact shape of this curve depends upon the region of the field magnetization curve used for a given field current range. The actual speed-current and speed-resistance curve must be available for determination of the proper field rheostat resistance and wattage values. These curves are sometimes available from motor manufacturers along with recommendations of practical speed limits for a particular motor. A speed versus current and field resistance curve can be determined experimentally by the use of an ammeter and voltmeter to calculate resistance. Also field resistance could be determined with resistor decade boxes or ohmmeters.

Methods of Decreasing Speed: Any method that reduces armature countervoltage will reduce shunt motor speed. Thus reducing line voltage will reduce speed. Of course, field flux will decrease, too, which has the effect of tending to increase speed but the drop in armature voltage has a far greater effect on speed.

Voltage on the motor can be varied by means of an adjustable voltage supply such as is possible with ac motor-dc generator sets or rectifiers. These will be discussed in greater detail later.

Speed can be lowered simply by adding an adjustable resistor into one side of the line, *Table* 12. Reduction of speed to about 50 per cent of base is considered a practical minimum especially for larger motors. Although control equipment cost is low, efficiency and speed regulation are poor because the field is weakened, too.

Better control is possible with an adjustable resistor placed in series with the armature, *Fig.* 20. Although the practical and economical speed range is still only about 2 to 1, motor speed stability is somewhat improved. However, speed regulation is often as high as 50 per cent at the low speed. Of course, the method could only be used on motors up to 40 or 50 horsepower because of the limitations of rheostat size.

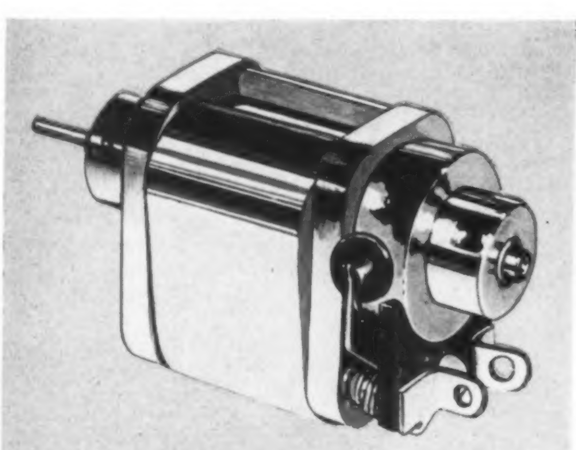
Shunt motors may be successfully reduced to about 10 per cent of base speed by shunting the armature with a resistor in addition to a resistor in series. This greatly improves speed regulation over what it would be if the speed were to drop to 10 per cent of base with the armature series resistor alone. Of course, efficiency is quite low since appreciable power is dissipated in the resistors.

Addition of series and parallel resistance to the armature circuit of a direct-current motor is especially applicable to motors used intermittently for low speed service and where resistor power losses are not of great enough importance to warrant a more elaborate speed-control system.

Combination Armature and Field Current Control: Wider speed range can be provided by combining both armature and field resistor control with the two methods described previously. A practical range of 8 to 1 for armature series resistor and field series resistor is then possible. Speed regulation is about 25 per cent at 400 per cent base speed, about 10 per cent at base speed, and 50 per cent at low speed. This type of drive is a constant-torque, variable-power drive below base speed and a variable-torque, constant-power drive above base speed.

Speed range could conceivably be extended to 20 to 1 by having a combination of resistors shunting the armature, in series with the armature, and

Fig. 21—Permanent-magnet motor, ¾ by ⅞ by 1⅜ inches, rated at 1/500-hp. Such motors operate up to 20,000 rpm



Photo, courtesy Small Motors Inc

Fig. 22—Current, speed, torque, power, and efficiency characteristics of 26-v dc permanent-magnet motor

Photo, courtesy Barber-Colman Co.

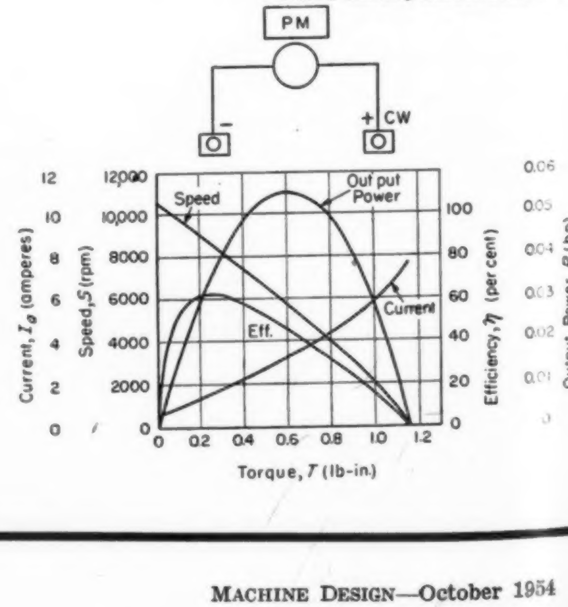


Table 12—Rheostat Speed Control of Motors

Control Method	Motor Type	General Characteristics of Control
Motor Series Rheostat	AC Series AC Shaded Pole AC Repulsion DC Compound DC Series DC Shunt DC Permanent Magnet Universal	Most used for ac or universal, fractional-horsepower appliances, where the load is constant or variations in speed with load are unimportant. Speed varies widely with the load. 50 per cent reduction of full-load speed is maximum used on larger motors — more on smaller motors — dependent on type of load.
Armature Shunt Rheostat	AC Series DC Series Universal	Reduces speed but maintains torque. Speed varies less widely with the load than with motor series control. 50 per cent reduction of full-load speed is maximum used on larger motors — more on smaller motors—dependent on type of load.
Combined Armature Shunt and Series Rheostats	AC Series DC Series Universal	Widest speed range—maintains torque. Useful where load varies. Speed remains fairly constant regardless of load. Range of 5 to 1 or more is possible depending on type of load.
Field Rheostat	DC Shunt DC Compound*	Most used type for integral-horsepower industrial applications. Speed remains fairly constant at any load. Speed increases with added resistance. Range depends on motor design. Field must never be opened.
Armature Series Rheostat	DC Shunt DC Compound*	Used to lower speed. Speed varies with load. Speed decreases as resistance is added. 50 per cent maximum on larger motors.
Combined Field and Armature Series Rheostats	DC Shunt DC Compound*	Used for widest speed range. Speed variation with load depends on position of control. Speed range depends on motor design.
Rotor Series Rheostats	AC Polyphase Wound Rotor	Standard method for wound rotor motors. Also used on single-phase type. Speed varies with the load. 50 per cent reduction in speed is the maximum generally used, though greater reduction is possible.

Data, courtesy Ohmite Mfg. Co.

* General characteristics of control apply to shunt motor. Each specific design of compound motors must be considered separately.

in series with the field. But manual control would be difficult and possibly dangerous.

Basic equations are listed in *Table* 2 for shunt motors.

PERMANENT-MAGNET MOTORS

The permanent-magnet motor, *Fig.* 21, can operate on only direct current and has characteristics similar to the shunt wound dc motor. Characteristics of a typical permanent-magnet motor are shown in *Fig.* 22. The permanent-magnet motor is somewhat more efficient than a shunt wound motor because no electric power is required from the line to produce the motor field. There is renewed interest today in the permanent-magnet motor because of the availability of higher practical power sizes and smaller physical sizes for the same horsepower. Better magnetic materials have produced these improvements.

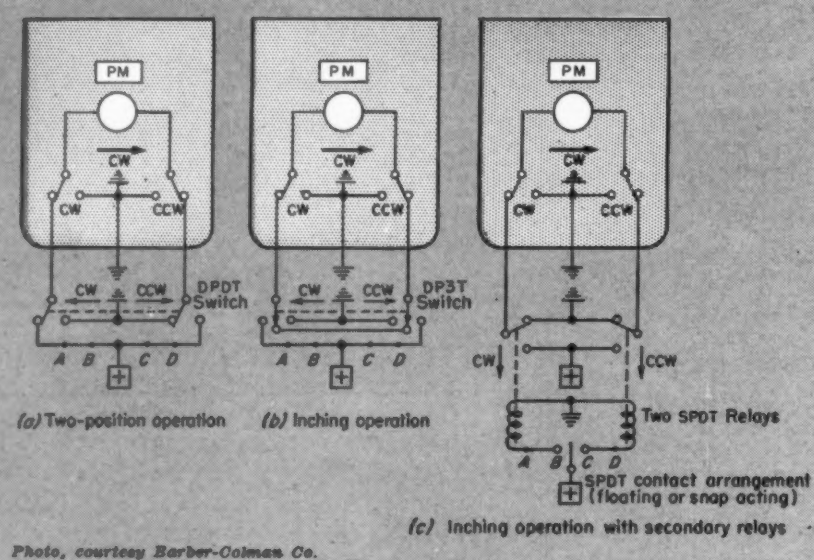
The permanent-magnet motor can be electrically adjusted in speed by an adjustable voltage supply or by inserting resistance in series with the armature, *Table* 2 (*k*) and (*l*). Speed of the permanent-magnet motor varies in almost direct proportion to input voltage at a given torque load. For example, at small torque loads, if the voltage on a 26-volt motor is adjusted from 8 to 40 volts, speed values corresponding to this voltage range may vary from 3000 to 15,000 rpm.

The permanent-magnet motor can only be used on light loads at lower voltages since stall torque varies almost in direct proportion to input voltage.

Reversing and Braking: Permanent-magnet motors can be reversed by reversing the direct-current input voltage polarity as shown by the three methods in *Fig.* 23. Small permanent-magnet motors can be dynamically braked by shorting the brushes, *Fig.* 23. With resistance inserted in series with the positive side of the line in *Figs.* 23*a*, *b*, *c* or reducing voltage, speed can be adjusted in either direction. If separate adjustable resistors are placed between points *A* and *B* or *B* and *C* in *Figs.* 23*a*, *b*, *c*, speed could be separately varied for each direction of rotation.

COMPOUND MOTORS

In the compound motor, speed variations due to load changes are much less than occur with the series type motor and greater than the shunt type



Photo, courtesy Barber-Colman Co.

Fig. 23—Methods of reversing and braking permanent - magnet motors

motor. The compound motor has a narrower adjustable speed range than the shunt motor, but starting torque is greater and the motor can withstand heavier overloads. The compound motor is not particularly well suited for applications requiring speed variation by means of field weakening. With a weakened shunt field, the series winding provides a larger percentage of the total field; thus the motor has abnormally high regulation—sometimes 25 per cent or more. Motors of this type have a maximum speed of about 125 per cent by field weakening.

Standard motors of this type have a cumulative compound winding; the differential-compound winding is limited to special applications. Compound motors find application where starting loads are heavy or where loads are changed suddenly and violently such as in printing presses, punch presses, and reciprocating pumps.

Formulas for some basic speed-control methods are tabulated in *Table* 2 (*m*), (*n*) and (*o*) and general characteristics in adjustable-speed operations are shown in *Tables* 9 and 12 along with typical applications.

ADJUSTABLE-VOLTAGE MOTOR-GENERATOR DRIVES

Although portable motor-powered equipment and transportation equipment almost always have dc power available, most industrial and commercial power systems supply only ac power because of distribution economy. However an ac system presents a problem when dc motors are required. To solve this problem, a number of ac-to-dc conversion systems, and many methods of controlling input and output, have been developed. Next have come standard "packaged" adjustable-speed drives built in quantity with resultant cost reduction. These drive systems provide adjustable dc voltage outputs for dc motor speed control.

The ac-to-dc conversion units and speed-control equipment may be in one unit or in a number of units. These adjustable-voltage drives have developed to the point where they can be easily integrated into the original design of a complete machine. Many of these drives are built for completely automatic motor-speed control and regulation. Often all that needs be added to them is a suitable transducer to change operating constants into mechanical, hydraulic, pneumatic or electrical signals that will actuate internal controls in the drive package. These control signals can act to accelerate or decelerate motor speed at a fixed rate, accurately regulate speed through wide load fluctuations, and synchronize several motors and operations such as encountered in automation lines.

Since the output voltage of these drives is usually controlled from voltage or current signals, control components can be easily modified to fit particular application requirements. Packaged units are often constructed from basic prewired subassemblies. For each particular application, the required type and number of subassemblies are rack or panel-

mounted with the necessary accessory controls added. Thus with control components and subassemblies that are already designed and field tested, custom-built drives are not prohibitive costwise. These drives are available for motors in the fractional horsepower sizes up to hundreds of horsepower.

Packaging also has other advantages: easy shipment, handling, and simple installation. Also, electrical components and equipment are protected from dirt, dust, flying debris, flying liquids, corrosive elements, etc. The packaged units are usually fan cooled with air drawn through heavy filtering material.

Ac-to-dc power conversion in these drives is accomplished either by motor-generator sets or by rectifiers. Since one of the earliest methods of adjusting speed of dc motors, and one still widely used, is by means of the adjustable output voltage from a generator, motor-generator type drives will be discussed first.

The motor-generator type adjustable voltage drive is often referred to as the Ward Leonard system, *Fig.* 24. Basically this system consists of a dc motor powered by a dc generator which is mechanically driven by a prime mover (electric motor, steam engine, steam turbine, combustion engine, gas turbine, etc.). The generator field and the dc-motor field can be either separately excited from a rectifier or a dc generator, as depicted in *Fig.* 24, or self-excited. Speed of the dc motor is usually controlled by adjusting field strength of the generator field which in turn controls the generator voltage supplied to the motor. Wider speed ranges can be obtained by also providing field control on the dc motor.

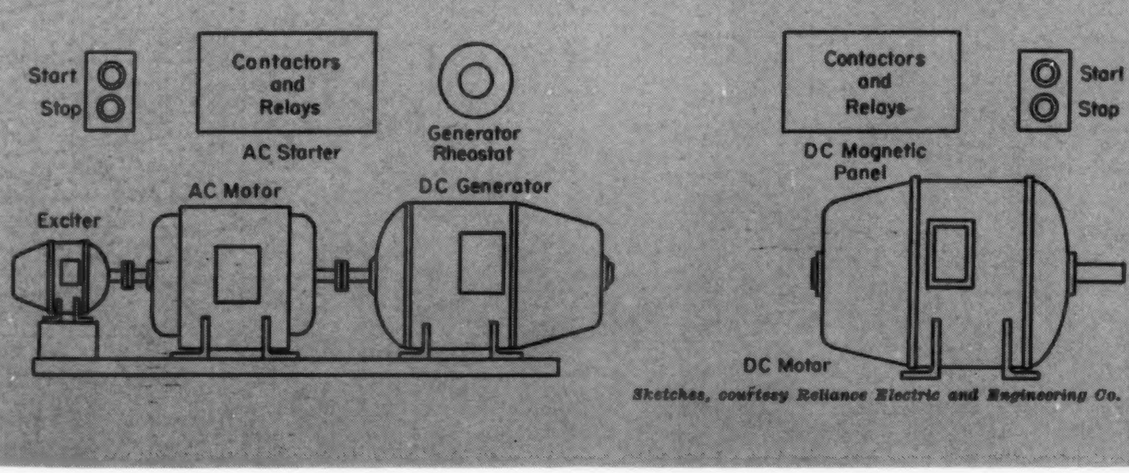
The prime mover today is frequently an ac motor because of the predominance of ac power in industrial and commercial power lines. Thus the motor-generator system is an effective method of not only providing wide-range speed control of dc motors, but it is also an effective means of converting alternating current to direct current. The motor-generator adjustable-voltage system has received considerable design and engineering attention in recent years. As a result, the basic system has gone through extensive development and refinement.

SELF-EXCITED MOTOR-GENERATOR DRIVES

Adjustable-resistance speed control of dc motors is restricted in application because of several limitations: (1) low overall drive efficiency at low speeds, (2) considerable heat generation at low speeds, (3) poor speed and torque regulation characteristics, and (4) difficulty of incorporating fast-responding automatic sequencing, synchronization and regulation control. These points are of little importance in many applications such as the electric lift truck, *Fig.* 10. However, where high-speed industrial and commercial applications are encountered, good efficiency and fast automatic speed control are often design requirements. Adjustable-voltage motor-generator drives can be designed to provide these features.

Series DC Generator and Motor: One of the simplest adjustable-voltage motor-generator drives employs a dc series generator and a dc series motor, *Fig.* 25. A practical speed range of 10 to 1 is possible with this arrangement by means of only

Fig. 24—Basic "conventional" Ward Leonard adjustable-speed drive. Controls consist of ac motor starter, rheostat speed adjuster, and dc motor starter



Sketches, courtesy Reliance Electric and Engineering Co.

a single rheostat. The range extends downward from base speed to 10 per cent of base speed. Since a series motor is utilized, starting torques of 300 per cent of full-load running torque and higher are often available. Speed regulation is about 15 per cent at the lowest practical speed and roughly 25 per cent at base speed. Practical generator rheostat size is the major factor which limits motor size to about 15 hp. This limitation stems from the fact that about 95 per cent of the full-load motor and generator current must flow through the rheostat at low speeds. The system has an essentially constant-torque characteristic. Regenerative braking is not possible with this system since the fields are in series with the armatures.

Shunt DC Generator and Motor: Because of the heavy current in the series type fields, the series system shown in *Fig.* 25 is usually satisfactory for only single-direction operation. Another adjustable-voltage drive offering greater flexibility and wider speed range—12 to 1—is shown in *Fig.* 26. This drive is made up of an ac motor driving a self-excited dc shunt generator which in turn provides adjustable voltage to a self-excited dc shunt motor. Speed can be reduced by 60 or 70 per cent by lowering generator field strength and regulation is about 20 per cent at the low speeds. Speed can be increased from 2 to 1 to 4 to 1, depending on the motor type, by motor field weakening. Speed regulation at the higher speed is approximately 25 per cent. Speed regulation at base speed is about 10 per cent.

SEPARATELY EXCITED MOTOR-GENERATOR DRIVES

Today most motor-generator adjustable-voltage drive systems are separately excited and are often referred to as "conventional" adjustable-voltage drives. They are more expensive than the self-excited adjustable-voltage drives, but their speed ranges are three to four times as great and horsepower is practically unlimited.

Separately excited fields permit great flexibility of speed control along with relatively high electrical to mechanical energy conversion efficiency. Generator voltage can be controlled by a rheostat in the generator field. If dc motor field voltage is held constant, nearly full torque is developed by the dc drive motor over a wide range of speed by simply adjusting the generator field rheostat. A speed range down to 10 per cent of base speed is easily obtainable. Of course, motors operating for prolonged periods of time at such low speeds under much of a load require forced air cooling of some type, *Fig.* 27, to prevent overheating. Speed regulation at this low speed may be as high as 50 per cent, but it must be remembered that this is an unregulated drive. If necessary, close speed regulation can be designed into this drive system.

For the conventional adjustable voltage system the most basic circuit with only generator-field

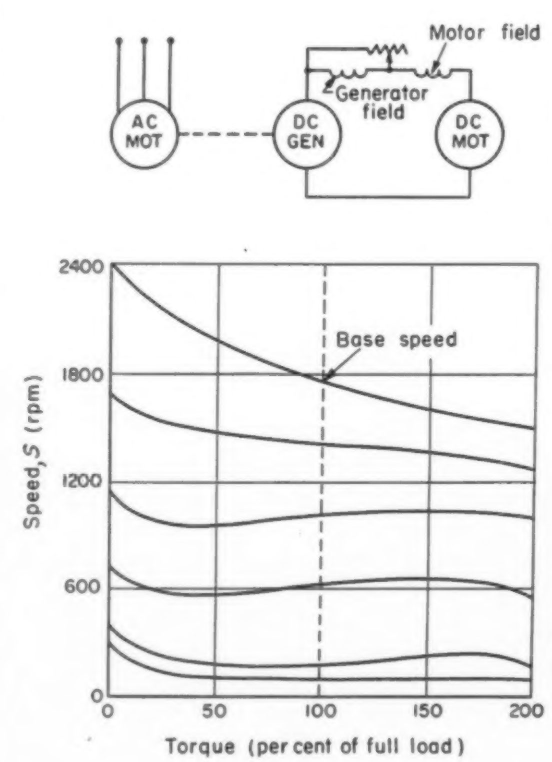
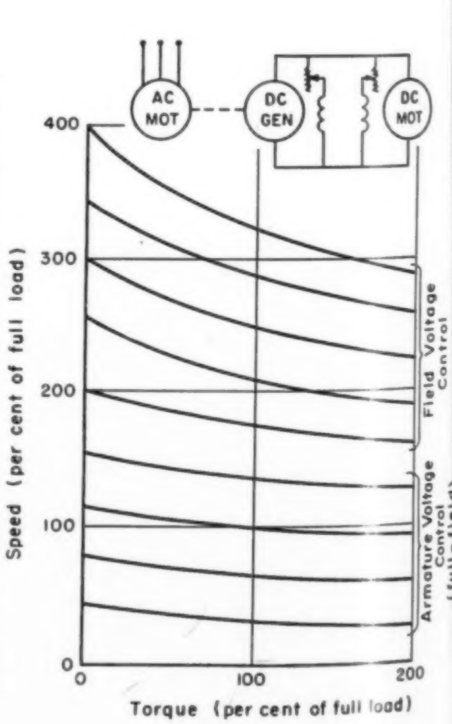


Fig. 25 — Left — Adjustable-voltage motor-generator drive employing a series type dc generator and dc motor. Typical speed-torque curves for six rheostat voltage settings are shown

Data, courtesy Westinghouse Electric Corp.

Fig. 26—Right—Adjustable-voltage motor-generator drive employing a self-excited shunt dc generator and dc motor. Speed-torque curves show wide speed range above and below base speed



rheostat speed control is shown in *Fig. 28a*. In *Fig. 28b*, a rheostat is added in series with the dc motor shunt field. By control of the motor field also, a speed range of 4 to 1 and higher above base speed is possible with about 25 per cent regulation at 400 per cent of base speed. Motor field adjustment here again gives effectively a constant-horsepower, variable-torque output.

Thus by a combination of controllable generator and motor fields, speed ranges of 40 to 1 and higher are easily obtainable. Frequently the generator and motor fields are controlled on tandem rheostats so arranged that the motor field is held maximum until the generator field has reached its maximum, after which the motor field can be weakened.

Reversing: In the conventional adjustable-voltage system, reversing the direction of motor rotation is accomplished in one of three ways:

1. Reversing motor armature leads, *Fig. 28c*
2. Reversing motor field leads, *Fig. 28d*
3. Reversing generator field leads, *Fig. 28e*

All three types of reversing can be employed with straight shunt motors. Either motor or generator field reversing is more economical in initial equipment cost than armature reversing for motors without series fields. This is true because motor armature reversing contactors must be heavy duty to handle full armature current while field contactors need handle only the much smaller field currents. However, from other standpoints armature reversing may be preferable.

For motors having both a series and a shunt field (compound or stabilized shunt types), usually only armature reversing is recommended. In this method, current in the series field does not change flow direction. Therefore, the motor shunt field flux and series field flux are always cumulative and the motor provides stable operation.

Reversing rotation by reversing either the motor or generator field must be used with discretion. In motor field reversing, the current in the armature and series field does not reverse and thus there is a series field flux differential to the shunt field which may produce an unstable motor. If the generator field is reversed, the motor armature current and series field current are again reversed, but the motor shunt field current is not changed in direction. Here, too, the shunt and series field flux of the motor are differential and the motor may be unstable. It is acceptable to jog-reverse series-shunt type motors either by generator field reversing or motor field reversing.

Jogging: In setting up processes, threading material into machines, etc., an independent low speed from the drive motor is often desired. This low speed which is termed inching, crawling, threading or jogging, is furnished by means of a transfer relay and contactors in the speed control circuit and a separate resistor, *Fig. 28f*, which may or may not be adjustable. Since only one of the generator field speed control resistors are ever connected at one time, the speed setting from one is not affected by the other.

Acceleration: The rate of acceleration of the dc drive motor is a function of (1) how fast the generator field voltage can be built up, (2) moment of inertia of the motor and its driven load, (3) limitations of commutation of both motor and generator, and (4) motor resistance to shock caused by high acceleration. The latter three points are independent of the generator voltage control, except generator commutation limitations, and thus are factors of motor selection. Thus, with a given motor, acceleration is controlled mainly by the rate of generator-field voltage build-up.

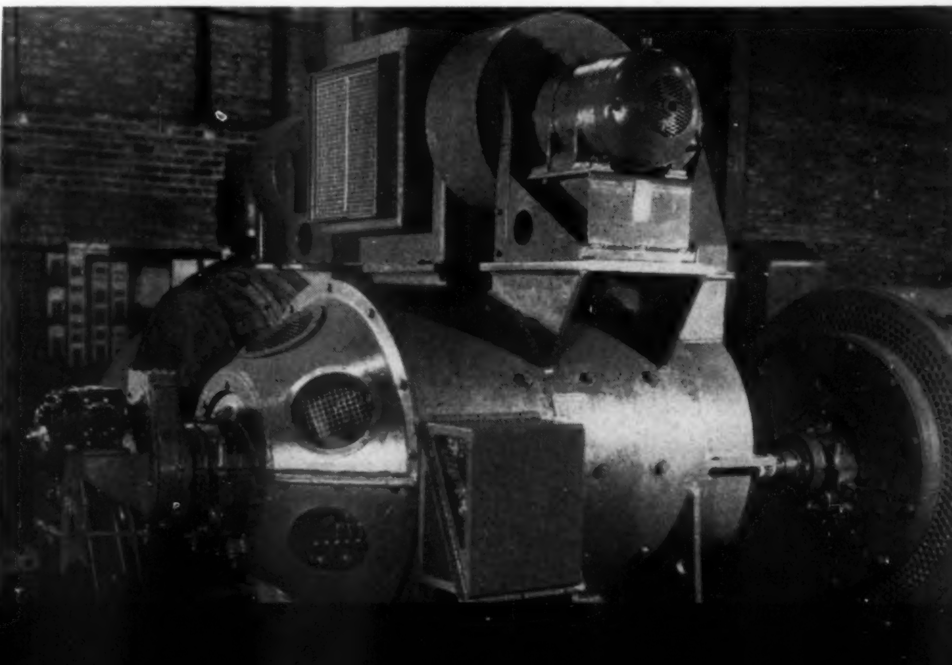
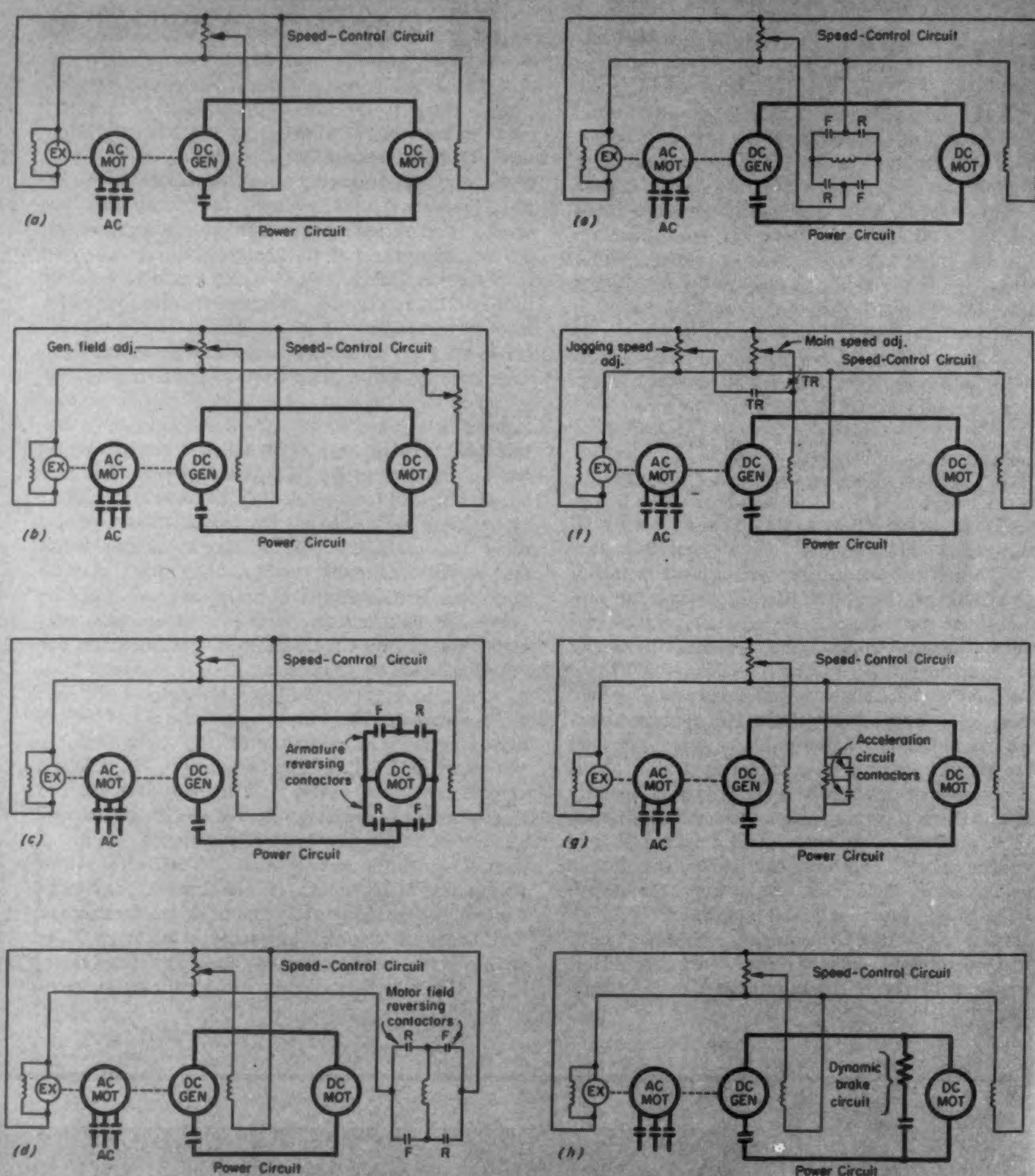


Fig. 27 — Adjustable-speed 300-horsepower dc motor with frame-mounted blowers to cool motor at low speeds

Photo, courtesy Allis-Chalmers Mfg. Co.



Sketches, courtesy Reliance Electric and Engineering Co.

Fig. 28—Conventional adjustable-voltage system circuits for dc motor speed control. Speed is controlled either by (*a*) generator field voltage adjustments, or (*b*) both generator and motor field voltage adjustment. Adjustable-speed drive motor rotation may be reversed by reversing dc motor armature connections, *c*, or field connections, *d*, or dc generator field connections, *e*. Preset speed jogging circuit is shown in *f*, and in *g* is a typical field-acceleration voltage control. Dynamic braking is accomplished by dc motor armature shunt circuit, *h*

Acceleration for many loads is controlled by an inherent time delay of the generator in building up to its preset value. For high inertia loads, however, or when automatic control of acceleration is desired, field accelerating relays, *Fig.* 28*g*, motor driven or manual rheostats, special regulators, or booster generators may be employed. With field accelerating relays, speed of generator field voltage build-up is controlled by the rate at which the field accelerator relays short-out fixed field series resistors.

Deceleration: Speed of the dc motor may be decelerated from high speed to low speed by any of the four methods used for acceleration: manual rheostat, motor-operated rheostat, timed control relay or regulators, plus several braking methods.

Dynamic Braking: In *Fig.* 28*h* a dynamic braking circuit is included. Where quick stopping is required, or where speeds must be reduced rapidly, dynamic braking is quite effective.

The dynamic brake circuit is simple and consists of a resistor in parallel with the armature and a contactor in series with this resistor. When the main contactor to the armature is opened, there is no current to the armature but the armature is still generating countervoltage. The dynamic braking contactor is closed, and current caused by the countervoltage of the motor flows through the resistance. The kinetic energy of the rotating parts is therefore dissipated as heat in the dynamic braking resistor. In small motors a dynamic brake may consist of a direct short circuit across the motor armature.

The dynamic braking effect diminishes as speed is reduced because countervoltage is likewise reduced and thus a smaller current flows through the dynamic braking resistor. Hence dynamic braking is rather ineffective at low speeds where the current is low. Braking effectiveness can be greatly improved by reducing the resistance value of braking resistor as motor speed decreases in order to keep the current through the resistor relatively high. The dynamic brake circuit is often used to prevent creep during equipment change and set-up periods.

Regenerative Braking: Another method that can be utilized to stop a motor quickly or to slow it down rapidly is regenerative braking. It is perhaps the simplest of the two electrical methods mentioned thus far. In regenerative braking the generator field strength is reduced by changing the field control rheostat. When the generator field

Fig. 29—Below—Methods for reducing or cancelling residual magnetism, permitting lower minimum speeds in motor-generator adjustable-voltage drives: (*a*) counterwinding connection, (*b*) "suicide" connection, and (*c*) combination main and "suicide" field connection

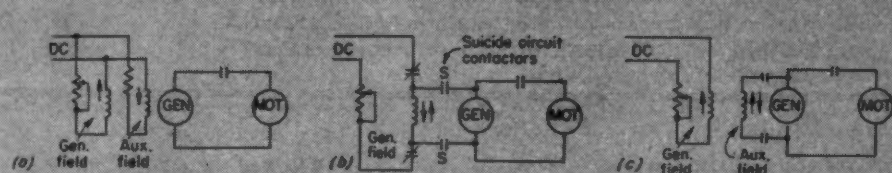
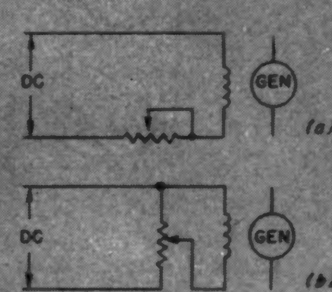


Fig. 30—Right—Series rheostat connection, *a*, which limits adjustable-voltage drives to 5 or 6 to 1 speed ranges. Potentiometer rheostat connection, *b*, permits wider speed ranges



Sketches, courtesy Reliance Electric and Engineering Co.

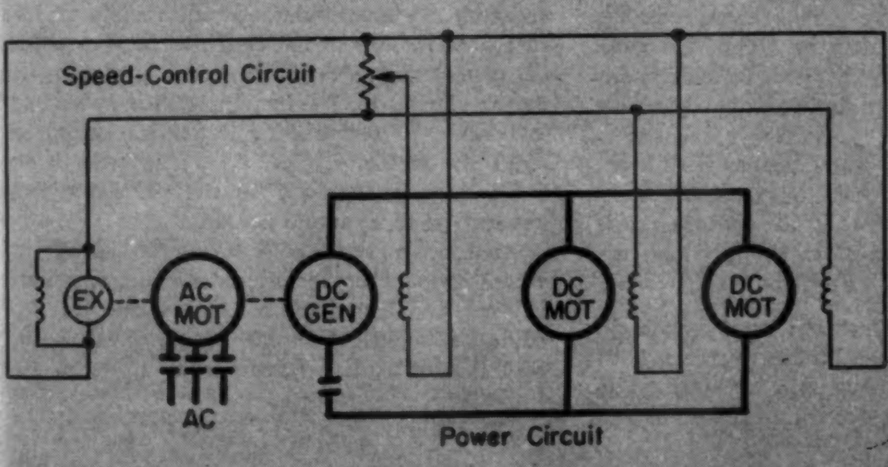
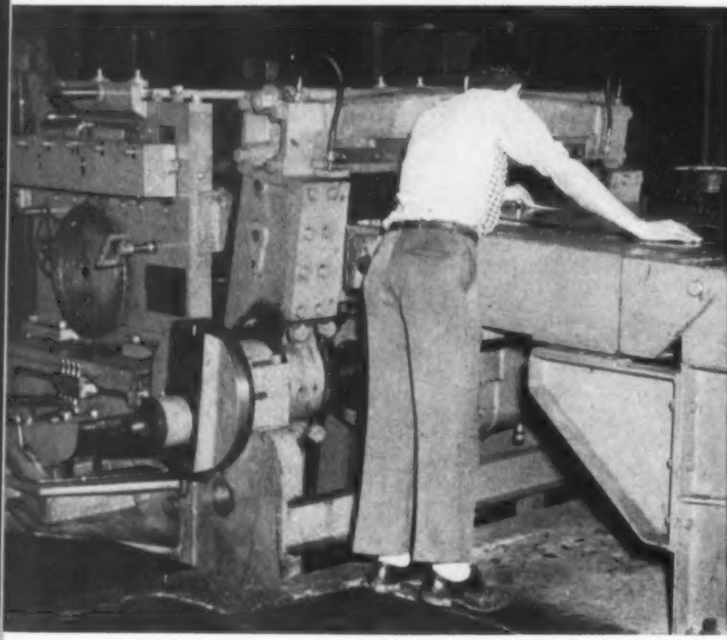


Fig. 31—Basic motor-generator circuit for multiple-motor dc drives



Photos, courtesy General Electric Co.

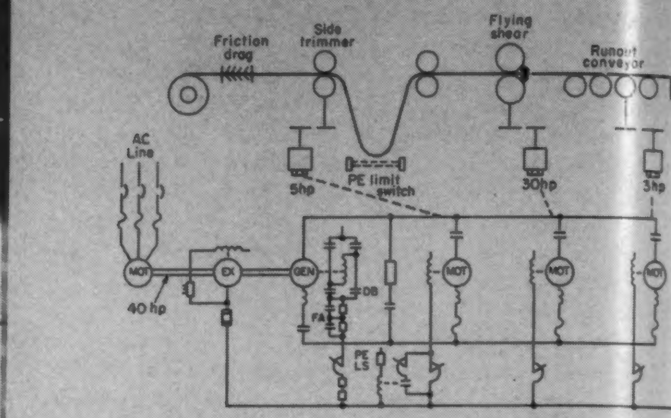
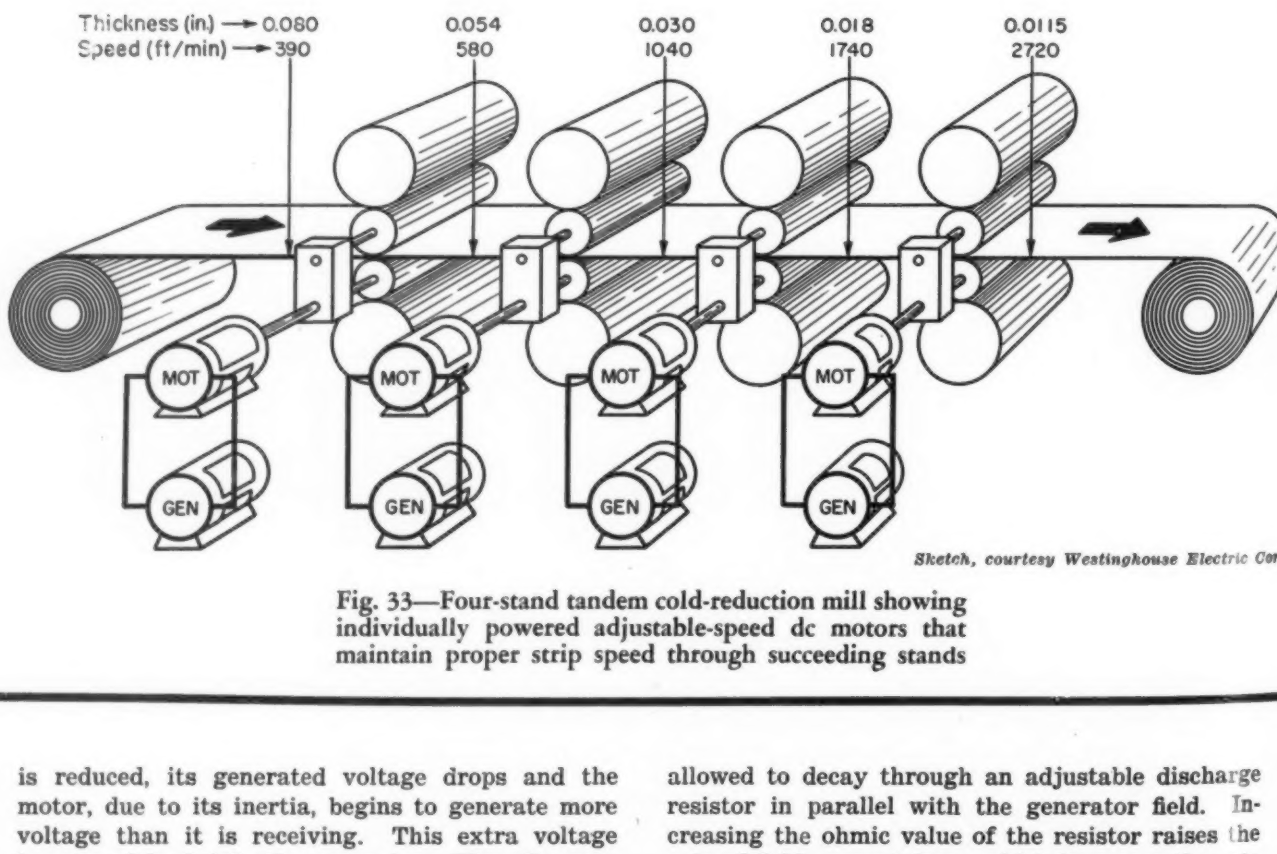


Fig. 32—Wean Engineering Co. steel mill shea drive with adjustable-speed multiple motor Photoelectric cell arrangement governs speed o line by a constant-sag method



Sketch, courtesy Westinghouse Electric Corp.

Fig. 33—Four-stand tandem cold-reduction mill showing individually powered adjustable-speed dc motors that maintain proper strip speed through succeeding stands

is reduced, its generated voltage drops and the motor, due to its inertia, begins to generate more voltage than it is receiving. This extra voltage is pumped back into the generator. Thus the generator serves much the same purpose of a dynamic braking resistor in placing an electrical load on the motor.

Regenerative braking is not possible with electronic, magnetic amplifier, or adjustable transformer type drives because they all contain rectifiers which permit current flow in only one direction.

Combination Electrical Braking: Another simple and effective method of fast braking utilizes both regenerative braking and dynamic braking. The generator field is cut loose from its excitation and allowed to decay through an adjustable discharge resistor in parallel with the generator field. Increasing the ohmic value of the resistor raises the rate of field current decay which increases the rate of generator voltage decrease, providing faster motor slow-down. When the motor is slowed to a low value, a conventional dynamic braking circuit stops the motor. Either time delay relays or voltage relays can be used for the transition from regenerative to dynamic braking.

Another method of braking is "plugging" in which the motor terminals are quickly reversed. In fact the reversing method shown in *Fig.* 28*c* could be called plugging. Plugging can be used in combination with dynamic braking.

Residual Voltage Problem: Theoretically the volt-

age across the armature of a dc generator in an adjustable-voltage system should be zero at rated speed when no voltage is being applied to its separate field winding. Actually there always is a small voltage developed by residual magnetism flux in the generator field poles and generator frame. For example, on a 250-volt generator the residual voltage may be about 10 volts, depending upon the design of the generator and the degree of saturation during the previous operating period.

In a Ward Leonard speed-adjustment system, residual voltage is a hindrance because it prohibits obtaining exceedingly low speeds. Thus, some means is often provided to counteract this voltage. Three circuits that are employed to accomplish residual flux cancellation are shown in *Fig.* 29.

COUNTERWINDING CONNECTION: One residual flux cancellation method is shown in *Fig. 29a* uses a counterwinding having polarity opposite to that of the main field. Regulating the current through the counterwinding reduces or eliminates residual voltage.

"SUICIDE" CONNECTION: A second technique for reducing the residual flux is known as a "suicide" field connection, *Fig. 29b*. By contactors, the generator field is removed from the excitation source and is placed across its own armature in such a manner that a voltage is generated in opposition to the residual voltage. The circuit thus kills off its own voltage.

COMBINATION MAIN AND SUICIDE FIELD CONNECTION: Recently a third circuit design, which is under an English patent, has been developed to reproduce a definite low-value countervoltage irrespective of the amount of residual flux. This system shown in *Fig. 29c* is composed of two fields on the generator. One field is the conventional main shunt field while the other is a relatively small auxiliary field. The auxiliary field is excited across the generator armature terminals and it kills the generator voltage while the main field is excited in the normal direction. The result is a controllable low generator voltage independent of the residual flux that may be present.

Rheostat Influence on Speed Range: When a rheostat is employed to control generator field excitation, it can be either the series type or the potentiometer type. The series type rheostat, which has a low initial cost, is connected as shown in *Fig. 30a*. However, the series type rheostat can only be used if the voltage range and thus the speed range is intended to be relatively narrow, such as 5 or 6 to 1. With this series type connection there is always some current flow through the generator field unless the rheostat is infinite in value.

If a wider speed range is needed, then the potentiometer type rheostat is used and connected as shown in *Fig. 30b*. The wider range is possible because with the rheostat finger at the extreme counterclockwise position, the voltage across the generator field and thus the current through it are zero. Obviously, the voltage applied to the generator field is reduced to zero which permits speed ranges as wide as are practical when aided by residual-voltage control.

MULTIPLE-MOTOR DRIVES

With the motor-generator system two or more dc drive motors may be operated in tandem and powered by the same generator, *Fig.* 31. The motor speeds may be varied simultaneously from one central speed adjuster in the generator field circuit. Such motors may apply power to several points in a machine, such as a long conveyor, or the striking example shown in *Fig.* 8. In such systems compound types of motors are often employed. On some multiple-motor drives, such as used on the shear drive in *Fig.* 32, individual speed adjustment can be provided for each motor by individual motor field adjustment. Sometimes variations in speed requirements of continuous-process machines are so great that individually powered dc motors must be employed, *Fig.* 33. Here strip output speed is nearly seven times as great as input speed.

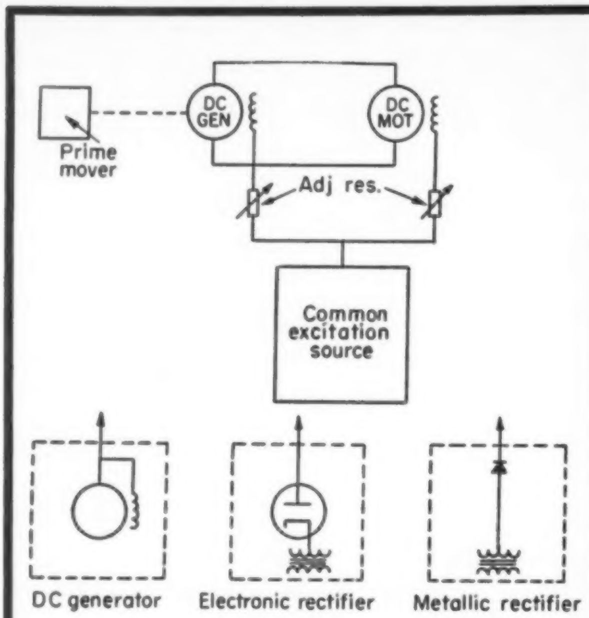
FIELD EXCITERS

In conventional adjustable-voltage drive systems, some means must be provided for supplying the separate dc power in the conventional Ward Leonard or adjustable voltage system required for field excitation. The problem is how, conveniently and efficiently, to provide separate dc power since the system is usually operating from an ac source.

One method is to couple mechanically another smaller dc generator to the ac motor that drives the main dc generator. This technique is commonly employed and these smaller dc generators are referred to as rotating exciters.

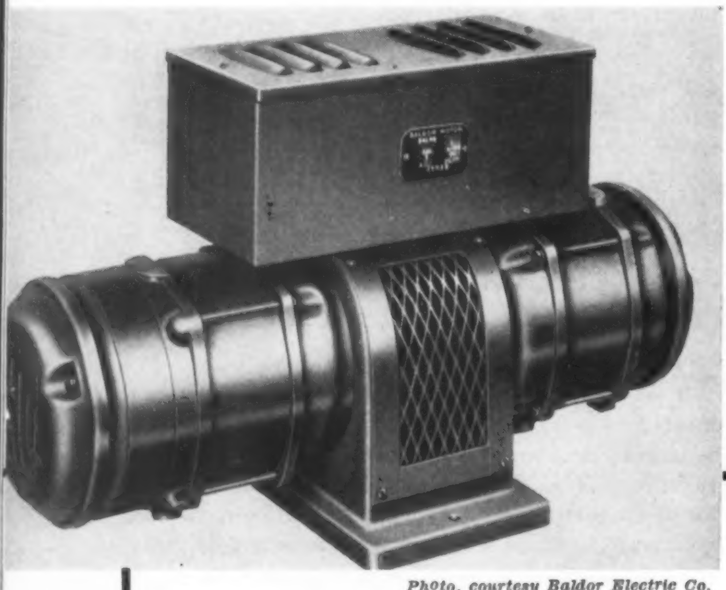
Another method is to feed ac current to rectifier systems and use the resulting dc current for field excitation. The most common types of rectifiers used for motor and generator field excitation applications are the electronic and metallic dry-plate rectifiers.

Any of these three types of exciters can be designed to supply an essentially constant voltage. Under these conditions field excitation can be sup-



Sketch, courtesy Century Electric Co. and Square D Co.

Fig. 34—Conventional adjustable-voltage drive system and three different kinds of field excitation sources



Photo, courtesy Baldor Electric Co.

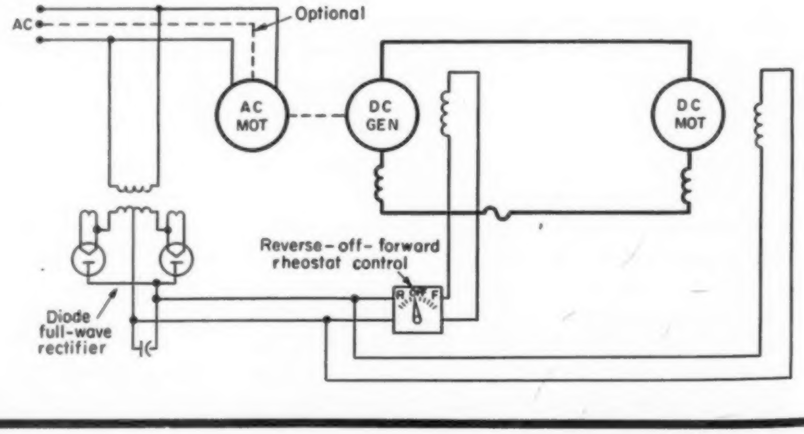


Fig. 35—Electronic rectifier exciter mounted on motor-generator power unit and basic drive circuit

plied by a single source and controlled by rheostats of the series type or potentiometer type in the generator field circuit or generator and motor field circuit. These three methods as applied to a conventional adjustable-voltage system are symbolized in *Fig.* 34.

Rotating Exciters: In *Figs.* 24, 28, 31 and 32 the field voltage exciters shown are the dc generator type. These rotating exciters are either directly driven by a motor-generator shaft extension, *Fig.* 24, or mounted above the motor generator set and belted to the ac drive motor.

Advantages of the rotating exciter are electrical simplicity, constant speed independent of changes in ac line voltage, and low initial cost. Adjustable-voltage drives with rotating exciters are often specified to provide an added safeguard against short-time power failures of a few seconds or even a few cycles. The rotating armatures in the ac and dc motors plus the main dc generator and the rotating exciter can nearly maintain rated power output for several seconds. This safety feature can be quite important in continuous process applications. In contrast, electronic or dry-plate rectifiers stop supplying exciter voltage immediately when power is removed; thus, generator and motor field excitation would start to decay immediately. Moreover, with the electronic exciter, output current usually is not instantly available when power is restored because of the time delay generally built in for tube protection.

On the other hand the dc generator exciter with rheostat speed control is a somewhat less efficient excitation system than amplifier type exciters, and is not readily adaptable to incorporation as a pilot device for fast automatic control systems. Naturally these factors only become important where close speed regulation or automatic control are required.

Electronic Exciters: Small to medium-horsepower drives may employ simple electronic tube diode rectifiers instead of rotating exciters. The rectifier

form of exciter has control characteristics comparable to the rotating exciter. A typical commercially available drive with diode excitation and its circuit are shown in *Fig.* 35.

Advantages of the electronic type of exciter system include the elimination of one rotating machine, which in turn reduces weight, noise, vibration and sometimes maintenance.

Electronic exciters vary in output in direct proportion to variations in line voltage into the electronic circuit. Electronic tubes of any size require a short warm-up period before starting and restarting, but these factors are often unimportant.

The addition of only a few components and replacement of the diodes with grid-controlled tubes permits higher system efficiency and flexibility of control.

Metallic Dry-Plate Exciters: The third basic excitation source is the metallic dry-plate rectifier which may be copper oxide, copper sulfide, or selenium oxide—usually the latter. As a simple rectifier, a selenium stack rectifier serves in the same manner as the rotating exciter or the diode electronic tubes just discussed, with performance almost identical to the electronic rectifier. Again efficiency, regulation and automatic control limitations are comparable. However, where these factors are not important, this type of exciter makes a highly reliable drive, *Fig.* 36.

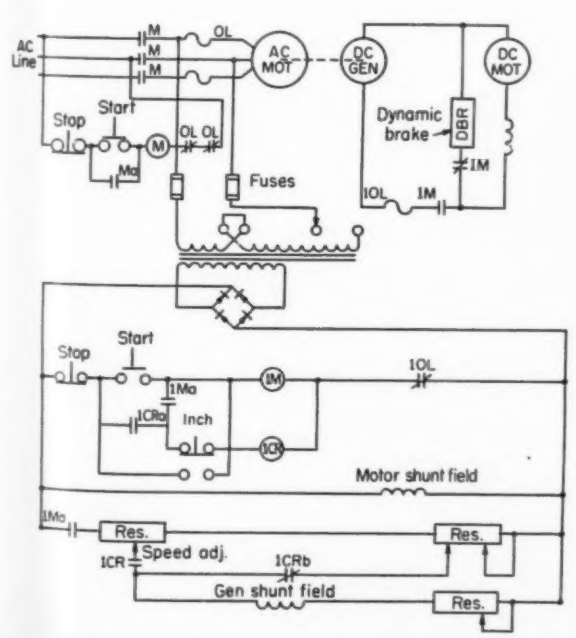
Selenium rectifiers have the advantage of requiring no time delay in starting and restarting. Also they do not require a center-tapped transformer for full-wave rectification. A basic full-wave metallic dry-plate rectifier is depicted in *Fig.* 37. Selenium rectifiers have an additional asset of a large short-period overload capacity; thus, little or no margin in current rating need be provided to handle starting requirements.

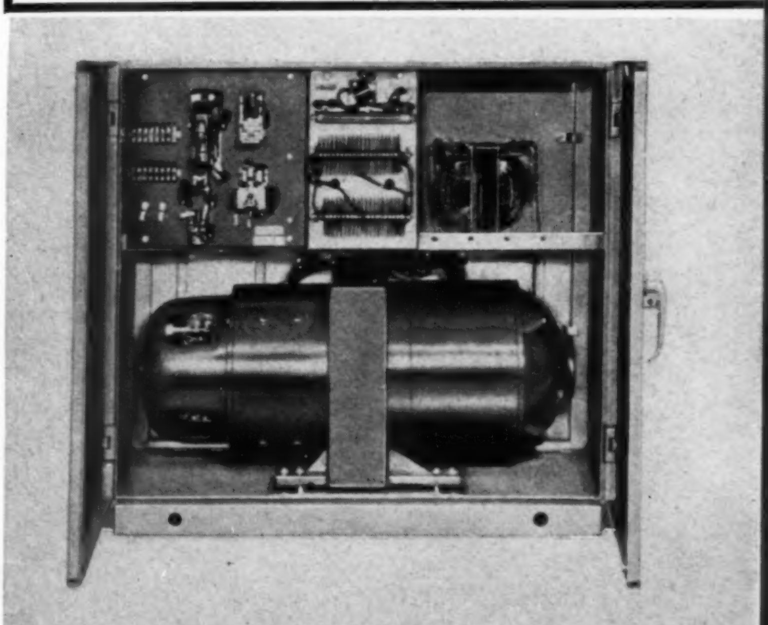
One drawback of selenium rectifiers is a slightly lower permissible operating temperature than that for electronic tubes. Temperature and life ratings of selenium rectifiers are given in many forms. For example, selenium rectifiers may have a 75 C maximum temperature rating per plate with a 35 C ambient temperature rating in a stack for operation carrying normal current. Load current must be modified if the stacks are placed in compact control boxes with poor ventilation. Otherwise stack ambient temperature may easily rise 15 or 20 C. Under these conditions, rated current may have to be reduced 40 or 50 per cent to prevent overheating of the plates. This reduction in permissible load current reduces output efficiency.

Progress is advancing rapidly in selenium rectifier design. Maximum temperature ratings of well over 100 C per plate are available today with stack temperature ratings for continuous operation in ambients above 45 C. Life expectancy of 15,000 hours and more for continuous operation at rated voltage and current at an ambient of 55 C, and 40,000 hours or more in a 35 C ambient are representative.

Thus, careful selection consideration must be given to each type of exciter, whether the designer is building the drive controls himself or buying a

Fig. 36—Adjustable-speed drive selenium rectifier exciter and motor-generator power unit and its nonreversing-drive circuit





Photo, courtesy Westinghouse Electric Corp.

package unit. Total drive costs are usually in the same order of magnitude for all three types of exciters.

AMPLIFIER TYPE EXCITERS

In the previous discussion, exciters were assumed to have an essentially constant voltage output and one exciter supplied excitation for both the main dc generator and the dc drive motor fields. With constant-potential exciters, speed control is obtained by individual manual or motor-operated rheostats in the field circuits.

In general, amplifiers operate on the principle that a small change in input power causes a large change in power output; amplification ratios of 1000 to 1 and higher are common. Amplifier type exciters provide the following advantages:

1. Increased electrical-to-mechanical power conversion efficiency when field excitation must be reduced.
2. Reduced size and power ratings on rheostats or other control devices.
3. Better automatic and semiautomatic control of motor and generator operating characteristics.

Actually the first two points might not warrant employing an amplifier type exciter because initial cost and maintenance cost might be higher than for the constant-potential exciter. However, the third factor justifies and often compels the application of amplifier exciters.

Here, too, there are three basic types of exciters commonly used:

1. Rotary amplifiers
2. Electronic amplifiers
3. Magnetic amplifiers

These amplifier-type exciters have been developed for independent excitation of both the motor and generator fields for the conventional adjustable-voltage drive system. The motor field strength in this system may or may not be adjustable and/or regulated, but the main generator field strength is always controlled and is usually regulated by any of a number of methods.

The three methods as applied to the conventional adjustable voltage motor-generator system are symbolized in *Fig.* 38.

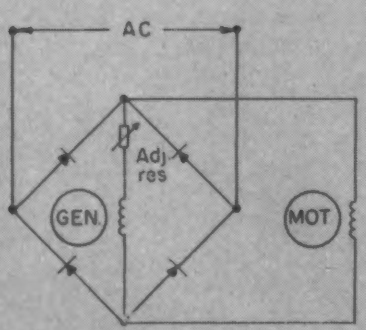
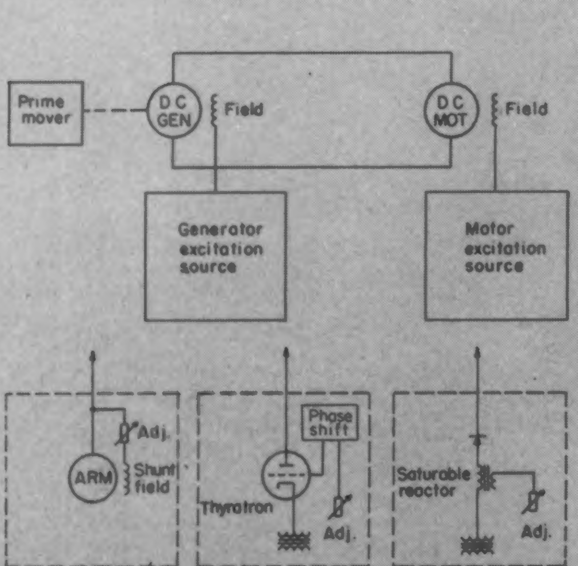


Fig. 37 — Basic full-wave bridge-rectifier circuit, employing the dry-plate metallic type, for adjustable field excitation

Rotating Amplifier Exciters: A dc generator exciter can be made to operate on the amplifier principle by simply placing a control rheostat in series with its self-excited field as depicted by the rotating exciter in *Fig.* 39*a*. A small resistance-value change in the exciter generator field circuit ultimately causes a large change in main generator voltage output, thus meeting the requirements of an amplifier. This method of speed control is



Sketch, courtesy Century Electric Co. and Square D Co.

Fig. 38—Left—Three amplifier type exciters for adjustable - voltage motor - generator drives

Data, courtesy Allis-Chalmers Mfg. Co.

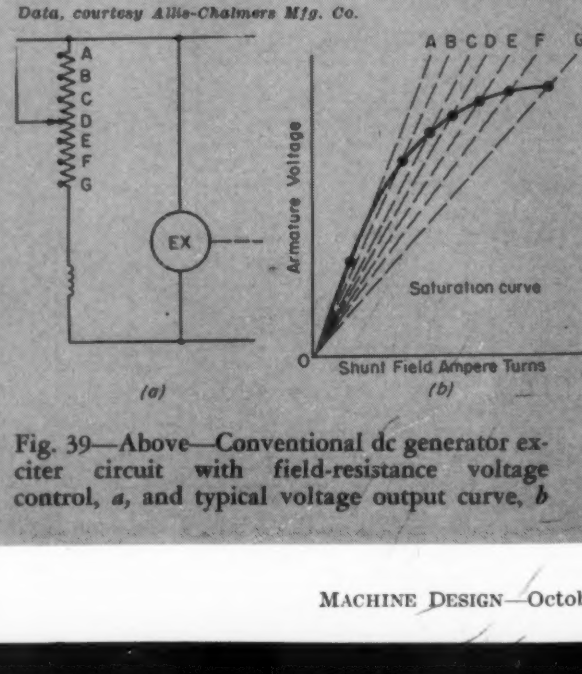


Fig. 39—Above—Conventional dc generator exciter circuit with field-resistance voltage control, *a*, and typical voltage output curve, *b*

sometimes used. Control rheostats, etc., are small and system efficiency is improved. Unfortunately, the ordinary generator has a saturation curve similar to *Fig.* 39*b*, giving a nonlinear output. This effect is then added to the nonlinearity of the main generator field. Also, if automatic control is needed, speed of response, ease of control, and accuracy are usually limited.

However, more effective amplifier type dc generators have been developed which contain a number of so-called control fields and other special design features. These units are referred to by a number of names including: rotating amplifiers, rotating controllers, rotating regulators, dynamic amplifiers, regulating exciters, regulating generators, and rotary amplifiers. Hence, from these terms come such tradenames for amplifier-type rotating exciters as Amplidyne (General Electric), Regulex, (Allis-Chalmers), Rototrol (Westinghouse Electric), and VSA (Reliance Electric). Since electronic amplifiers and magnetic amplifiers are also used in controlling and regulating field excitation, the new American Standard Y32.2-1954 on graphical symbols for electrical diagrams refers to this type rotating exciter as a "regulating generator (rotary amplifier)."

BASIC TYPES: Regulating generators as a group differ mainly from standard dc generators in that they usually have several separate field control windings to regulate output. Although each of the tradenamed regulating generator exciters differ somewhat in basic design, all of these units provide large output voltage changes from small input changes. The "self-energized" rotary amplifiers (Regulex, Rototrol or VSA) use shunt or series field excitation or a combination of both. These units employ as many control windings as are required—usually limited to four.

In one design of an amplifier-type rotary exciter, which is predominately field excited, *Fig.* 40*a*, a "tuning" resistor is added in series with the exciter field to limit field excitation to the straight-line portion of the magnetization curve in *Fig.* 39*b*. In addition the flux path is made large enough by greatly increasing the regulating generator frame thickness to prevent flux saturation within the rated voltage range. This results in the straight-line relationship of output voltage versus excitation of the exciter field, *Fig.* 40*b*. These regulating generators are often termed the self-excited type but they are also separately excited, for example, when used as booster generators in the field excitation circuit.

The shorted-armature type of regulator, *Fig.* 41, is mainly armature reaction excited. A small amount of control excitation establishes a small

Sketch, courtesy General Electric Co.

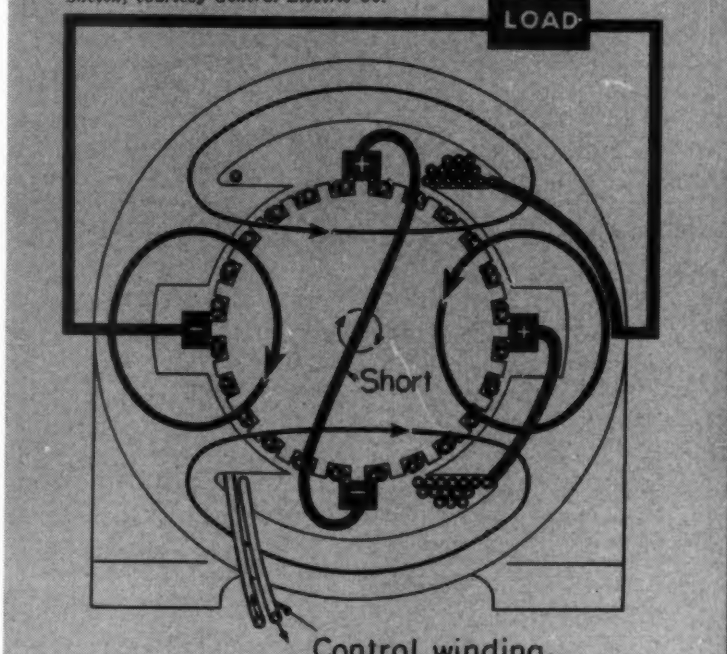


Fig. 41—"Armature-reaction" type regulating generator

Data, courtesy Allis-Chalmers Mfg. Co.

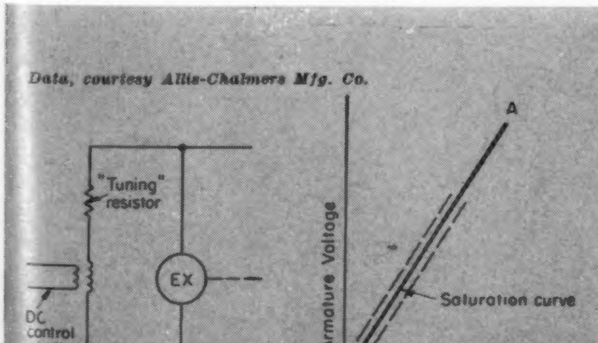
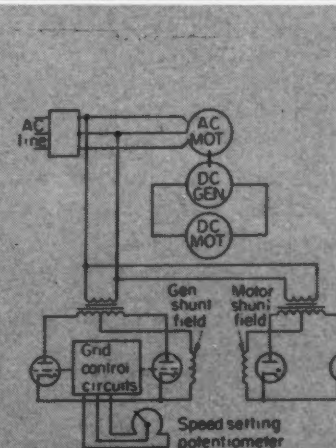


Fig. 40—Left—"Self-energized" type regulating generator (rotary amplifier) exciter circuit, *a*, and typical voltage output curve, *b*

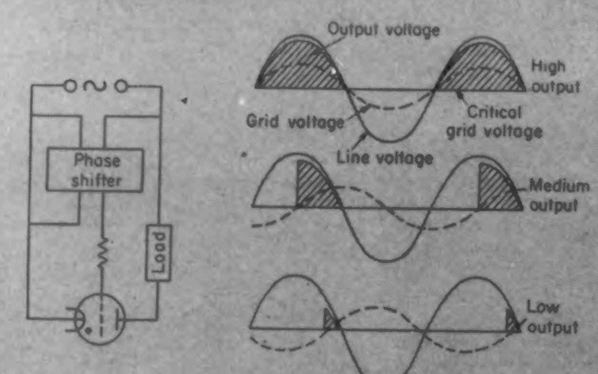
Fig. 42—Right—Basic circuit of grid-controlled electronic exciter applied to an adjustable-voltage drive



Sketch, courtesy Square D Co.

flux which causes a large current to flow through the short-circuited brushes. This current sets up a large armature reaction flux which results in a relatively large output voltage for exciting the main generator and motor fields. Although theoretical power amplification of thousands is possible, practical limitations dictate lower values.

Electronic Amplifier Exciters: By the addition of only a few standard components, grid-controlled electronic tubes may be utilized to supply excitation power for adjustable-voltage drives. A basic electronic exciter drive circuit with a grid-controlled rectifier tube is shown in *Fig.* 42. Power output of electronic amplifiers is often controlled by adjusting the phase relationship between plate voltage and grid voltage as shown for a half-wave rectifier in *Fig.* 43. This scheme permits control of the dc motor speed over a range of 8 to 1 or more by means of a small potentiometer. By the addition of grid control to the dc motor field rectifier, the speed range may be extended to 30 to 1 and higher. In the latter system both fields may be controlled from a single potentiometer unit. The speed controlling rheostat has a very low power rating because it is working in the low-power grid circuit to the electronic tube amplifier.

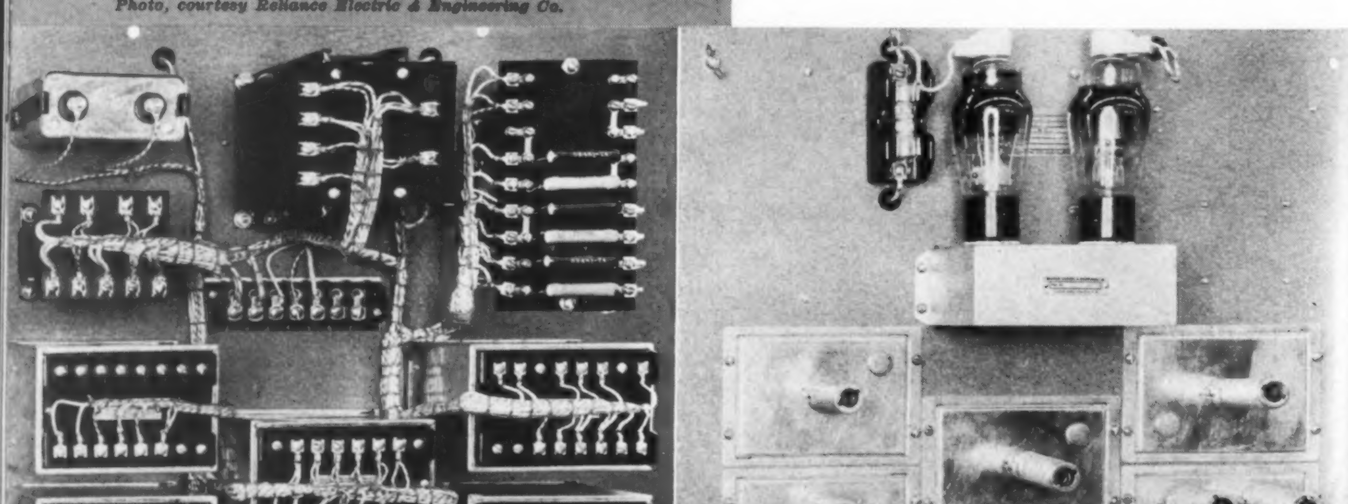


Sketch, courtesy Electrons Inc.

Fig. 43—Above—Basic circuit of a half-wave electronic amplifier rectifier and variations in output for different grid phase-shifts

Fig. 44—Below—Electronic-amplifier regulator for adjustable-voltage drives. Circuit subassembly design permits easy, quick replacement of portion of regulator circuit

Photo, courtesy Reliance Electric & Engineering Co.



Major advantages of the electronic amplifier include fast response, extreme sensitivity, light weight and flexibility of control. Triode type circuits are simple, and modern thyratron tubes usually give several thousand hours of dependable operation. From a flexibility standpoint, almost any drive requirement can be fulfilled. Close speed regulation, load compensation, control of acceleration and deceleration, and response to pilot devices in automatic control systems are easily obtainable.

From a maintenance standpoint the electronic amplifier is considered by many to be the easiest to maintain. If a tube burns out, it is often just a matter of looking for an unlit tube or feeling the tubes. However, when other circuit problems arise, it is just as difficult to service an electronic amplifier as a rotating amplifier or a magnetic amplifier.

The main drawback of electronic tubes is that although average tube life is long, the life expectancy of a particular tube or group of tubes is

often impossible to predict. This problem has been partially solved in a number of ways: (1) by long tube seasoning to reduce "infant mortality" rates (early burnout), (2) by using especially rugged tubes, (3) by having spare, easily connected chassis and subassemblies, *Fig.* 44, or (4) by using standby double circuitry where circuits automatically switch from an inoperative circuit to a second reserve circuit.

Electronically excited adjustable-voltage drives are marketed with the electronic exciter on the ac motor-dc generator set, *Fig.* 35, the electronic exciter in a separate package from the ac motor-dc generator set, *Fig.* 6, or the electronic exciter and motor generator and associated controls in a complete package, *Fig.* 45.

Magnetic-Amplifier Exciters: The amount of rectified ac load current through metallic dry-plate rectifiers can be controlled by adjusting the input voltage by adjusting circuit impedance. An adjustable autotransformer could be employed to provide adjustable input voltage but this technique is not ordinarily used for field excitation control in the conventional adjustable-voltage drive system.

Another method of adjusting output current through selenium rectifiers is to incorporate a controllable impedance in the circuit. To control impedance an adjustable resistance, capacitance, or inductance or combination of these could be utilized. Resistance control has been discussed previously and capacitance control is rather impractical at 60-cycle frequencies.

Adjustable inductive reactance control is commonly employed where amplifier type excitation is desirable. The simplest inductive device consists of a coil of wire but it offers little in practical inductive reactance control possibilities. However, by wrapping a coil of wire on an iron-core, inductance and in turn inductive reactance is not only relatively high but is easily controllable.

Coil inductance can be controlled by an adjustable air gap in the iron core, but this method requires manual or motor operation. Another method of adjusting inductive reactance which is rapidly gaining in popularity today in dc motor speed

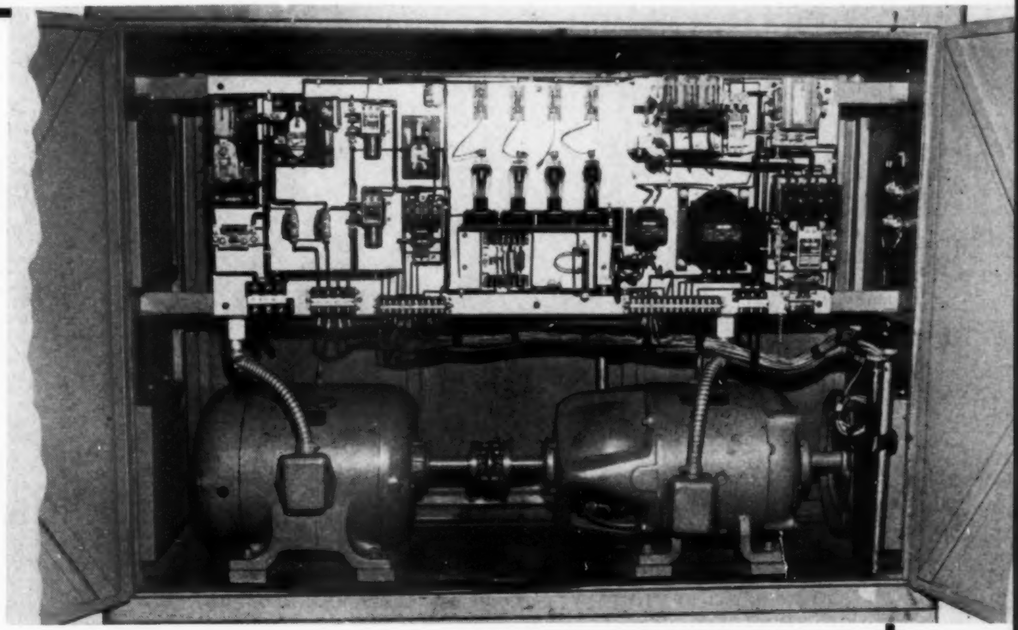


Fig. 45 — Packaged electronically - excited motor-generator drive power unit

Photo, courtesy Century Electric Co. and Square D Co.

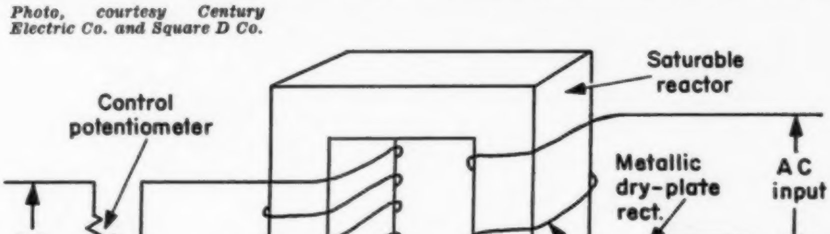
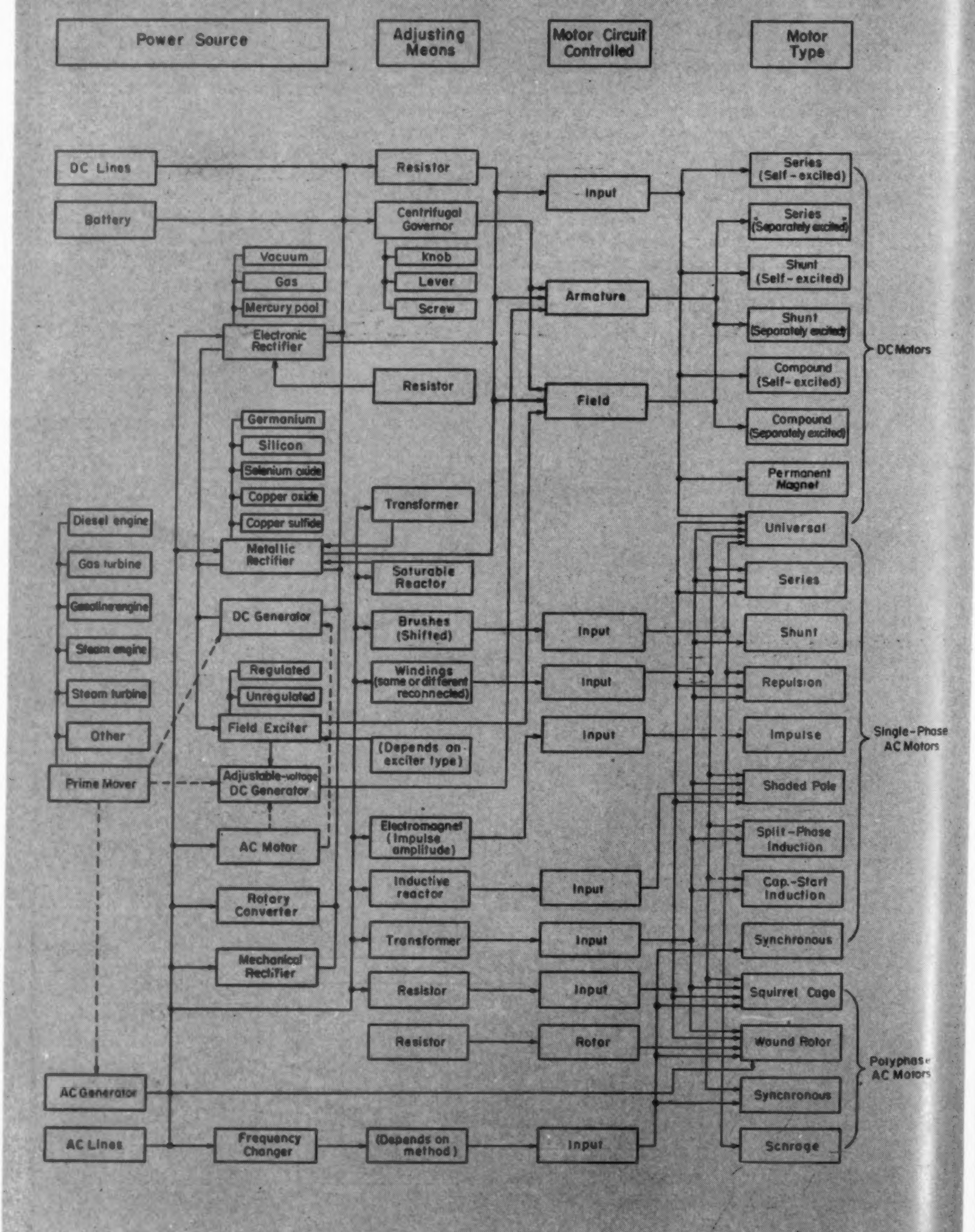


Fig. 46 — Basic half-wave magnetic amplifier circuit

ELECTRIC-MOTOR SPEED-CONTROL SYSTEMS



COMPARISON OF ADJUSTABLE-SPEED ELECTRIC-MOTOR DRIVES

Drives	Control Means	Speed Range (max.)	Output Power (hp)	Size (per cent)	Cost
DC Motors					
Series	Armature resistance	Depends on load	1 to 200 int.	100	Low
Shunt	Armature resistance	2/1	¼ to 50	100	Low
	Field resistance	6/1	¼ to 50	200 for 2 to 1 fld. adj.	Low
	Armature and field resistance	12/1	Any size	400 for 4 to 1 fld. adj.	Low
Compound	Same general methods as shunt	Depends on control method and motor	Any size	Depends on control method and motor	Low
Permanent Magnet	Armature resistance	2/1	Fractional	——	Low
AC-DC Motors					
Universal	Resistance	Depends on load	Fractional and to 2½	——	Low
	Centrifugal governor	12/1	Fractional	——	Low
	Brush shifting	Depends on load	Fractional	——	Low
AC Input Adj.-Voltage Types					
Self-Excited Series DC Generator and Motor	Shunt resistance across generator field	10/1	1 to 15	100	Medium
Self-Excited Shunt DC Generator and Motor	Field resistance of both generator and motor	12/1	to 15	Depends on motor field control	Medium
Separately Excited DC Generator and Motor	Field resistance of generator	60/1	Any size	100	Medium
Separately Excited DC Generator and Motor	Field resistance of both generator and motor	120/1	Any size	Depends on motor field control	Medium
AC Input Rectifier Types					
Electronic	Grid phase shifter	240/1	Any size	to 125	Medium
Magnetic-Amplifier	Saturable reactor	100/1	1/40 to 5	to 125	Medium
Adjustable-Transformer	Adjustable autotrans.	Limited only by motor design	1/15 to 100	100	Low
Single-Phase AC Motors					
Shunt	Adjustable autotrans.	4/1	Fractional	——	Medium
Repulsion	Brushes (Shifted)	4/1	¼ to 3	——	Low
Shaded-Pole	Resistance	4/1	1/2000 to 1/6	——	Low
	Reactance	4/1	Same	——	Medium
Split-Phase Induction	Windings (Reconnected)	2/1 up	1/500 to 5	——	Low
Capacitor-Start Induction	Windings (Reconnected)	2/1 up	1/5000 to 7½	——	Low
Polyphase AC Motors					
Squirrel Cage	Windings (Reconnected)	2/1, 3/1, 4/1	Any size	to 125	Low
	Primary resistance	Depends on load	to 20	——	Low
	Frequency	Depends on frequency range		——	High
Wound Rotor	Rotor resistance	2/1	Any size	——	Medium
	Primary impedance and secondary resistance	Depends on load	to 200 cont., to 300 int.	——	Medium
	Frequency	Depends on frequency range		——	High
Synchronous	Windings (Reconnected)	2/1	Any size	——	Medium
	Frequency	Depends on frequency range		——	High
Schrage	Brushes (Shifted)	20/1	to 500	to 150	Medium

TRADENAMES OF DRIVES WITH STEPLESS MOTOR SPEED CONTROL

Adjustable-Voltage Motor-Generator Drives

Allis-Chalmers Drive (1 to 200 hp) ....Allis-Chalmers Mfg. Co.
AV Drive (1 to 200 hp) .... Westinghouse Electric Corp.
Baldor Drive (¾ to 3 hp) .... Baldor Electric Co.
Select-A-Spede (1 to 200 hp) ....Louis Allis Co.
Selective Speed (1 to 150 hp) .... Century Electric Co.
Speedranger—Type GV (2 to 15 hp) ...... Master Electric Co.
Speed Variator (1 to 200 hp) .... General Electric Co.
V*S Drive (¾ to 300 hp) .. Reliance Electric & Engineering Co.

Electronic Drives

Arrow-Hart (Fractional hp) . Arrow-Hart & Hegeman Electric Co.
Dial-A-Speed (1/15 to 3 hp) .... Brown-Brockmeyer Co. Inc.
Erdco (1/20 to 2 hp) .... Erdco Engineering Corp.
Mot-O-Trol (⅛ to 30 hp) .... Westinghouse Electric Corp.
Select-A-Spede (¾ to 15 hp) .... Louis Allis Co.
Servospeed (1/300 to 3 hp) . Servospeed Div., Electro-Devices Inc.
Servo-Tek (Fractional hp) ...... Servo-Tek Products Co. Inc.
Servotron (¾ to 1 hp) .... Raytheon Mfg. Co.
Speedranger—Type EV (⅛ to 1½ hp) .... Master Electric Co.
Thy-Mo-Trol (1/70 to 30 hp) .... General Electric Co.
Vara-Speed (1 to 15 hp) .... Weltronic Co.
V*S Jr. (¾ to 3 hp) .... Reliance Electric & Engineering Co.
V*S Xatron (30 to 50 hp) ..Reliance Electric & Engineering Co.
C-25 and G-T-21 (Fractional hp) ...... Gerald K. Heller Co.
301-A and 301-B (1/100 to 1/20 hp)....Industrial Control Co.
6510 (1/3 to 30 hp) .... Clark Controller Co.

Magnetic-Amplifier Drives

Franklin Drive (¼ to 5 hp) .... Franklin Control Corp.
MA Drive (¼ to 3 hp) .... Magnetic Amplifiers Inc.
6520 (1/40 to ¾ hp) .... Clark Controller Co.

Adjustable-Transformer Drives

Electro Variable Speed (Fractional and 1 hp) Electro Products Laboratories Inc.
Variable Auto-Transformer (Fractional hp) Standard Electrical Products Co.
Variable Voltage Scienifier (1/15 to 100 hp) American Rectifier Corp.
Variac (1/15 to 1½ hp) .... General Radio Co.

Single-Phase Brush-Shifting AC Motor Drives

LK (1/6 to 3 hp) Star-Kimble Motor Div., Miehle Printing Press and Mfg. Co.
RV (¼ to ¾ hp) .... Leland Electric Co.

Polyphase Brush-Shifting AC Motor Drives

ACA (1 to 200 hp) .... General Electric Co.
AVC (1½ to 15 hp) .... Belgian Electric Sales Corp.
Brown-Boveri (1 to 500 hp) .... Brown-Boveri Corp.

Synchronized Multiple-Motor Drive Systems

Selsyn .... General Electric Co.
Syncro-Lock .... Reliance Electric and Engineering Co.
Syncro-Speed .... Century Electric Co.
Syncro-Tie .... Westinghouse Electric Corp.

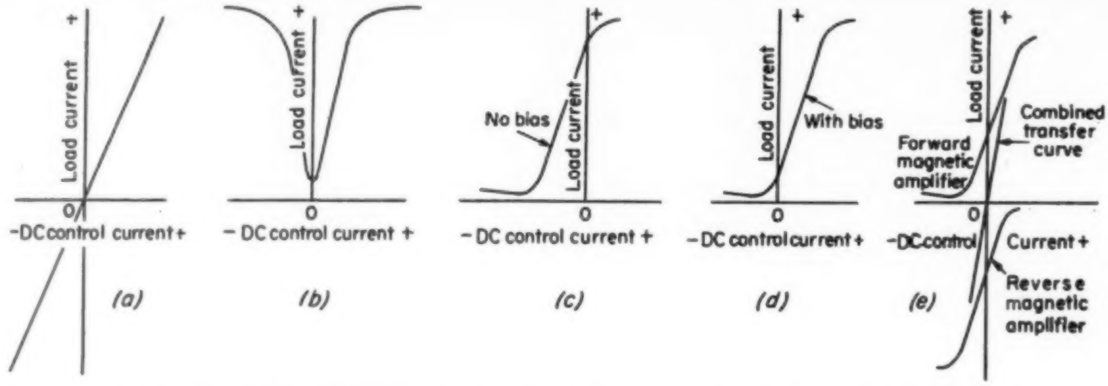
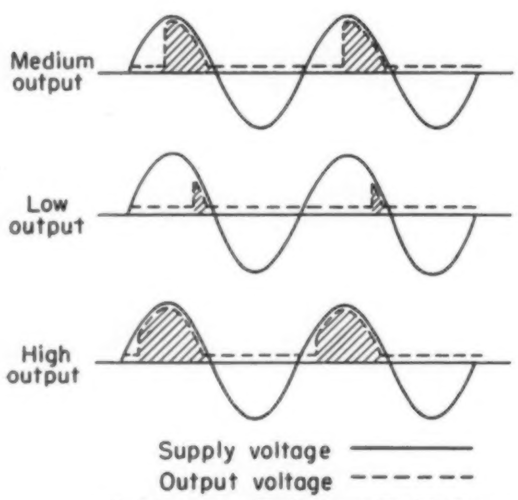


Fig. 47—Saturable, inductive reactor load current versus dc control-winding current: (a) ideal, (b) ordinary saturable reactor, (c) magnetic amplifier, (d) magnetic amplifier with bias, and (e) double magnetic amplifier



Sketch, courtesy Westinghouse Electric Corp.

Fig. 48—Waveform of magnetic-amplifier ac supply voltage and output load current for three operating conditions

control is to control flux saturation of the iron core. The basic device known as a magnetic amplifier is similar to a transformer and consists of a load or power winding and a control winding. For some applications of the magnetic amplifier, ac power may be applied to the control winding. However, for dc power control work, the control winding is energized with some form of direct current and a metallic dry-plate rectifier is incorporated in the load winding, *Fig.* 46.

The ideal field exciter would produce, among other things, linear negative and positive output voltage from negative and positive polarity control voltage, respectively, *Fig.* 47*a*. An ordinary iron-cored inductance and a rectifier in the load circuit produces a rather undesirable dc motor control

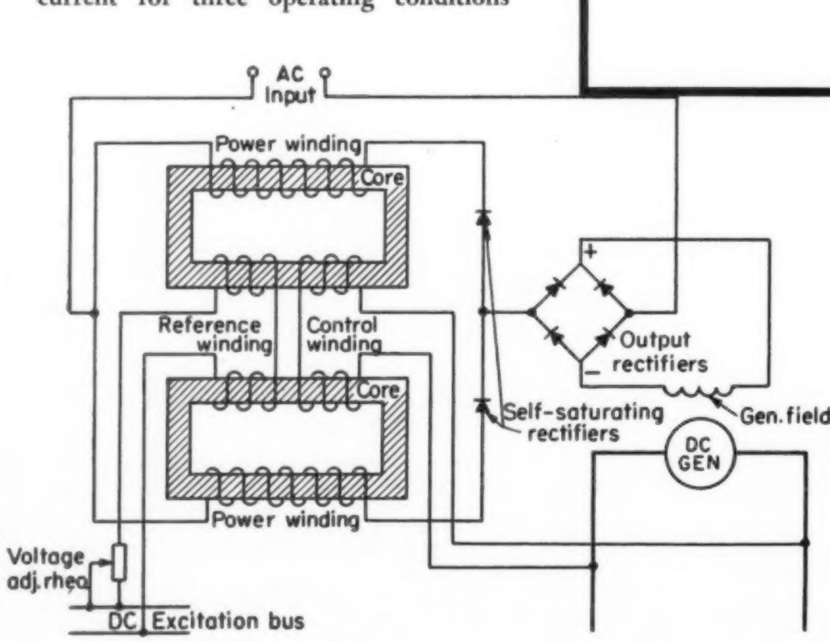


Fig. 49—Diagram of a basic practical magnetic amplifier with voltage feedback control winding

Sketch, courtesy Westinghouse Electric Corp.

characteristic similar to that shown in *Fig. 47b* for positive and negative input control. Through improvements in the design and application of iron-core materials and rectifiers, the practical magnetic-amplifier control curve in *Fig. 47c* can be obtained today. By adding a so-called bias winding the characteristic control curve is shifted to the right, *Fig. 47d,* so that output is low for low values of control current and increases with increasing values.

Since rectifiers are used to obtain dc output current to excite a field, where reversing control is required, it is necessary to use two independent magnetic amplifier circuits in a push pull arrangement, *Fig. 47e,* one for forward and the other for reverse operation. This necessitates two machine fields connected to oppose each other.

Output Current: The waveform of the output current of the magnetic amplifier used for dc power control is almost identical to that of the electronic amplifier except for a small finite value of load current due to the inability of the single stage magnetic amplifier to cut-off completely, *Fig. 48.* When the iron core saturates because of enough ampere turns developed by either the load winding or control winding, the increase in current flow is rapid. By limiting the power circuit load resistance and coil turns, load current is controllable through the control-winding ampere turns alone. Then, only a small change in dc control current produces a large change in average output load current.

Practical Basic Circuit: The elementary circuit in *Fig. 46* is not practical for general use because the ac supply frequently induces high voltage in the control winding which causes objectionable circulating currents to flow through the control winding. Also, average load current is low since the circuit in *Fig. 46* employs half-wave rectification.

A more practical form of magnetic amplifier is shown in *Fig. 49* which is an elementary type of voltage regulator employing generator terminal voltage feedback control. The use of two cores minimizes the effect of induced voltages since the two control windings are connected in opposition and any induced voltages tend to cancel each other. The generator field is connected in a rectifier bridge circuit so that full-wave rectification occurs and average value of current is considerably higher

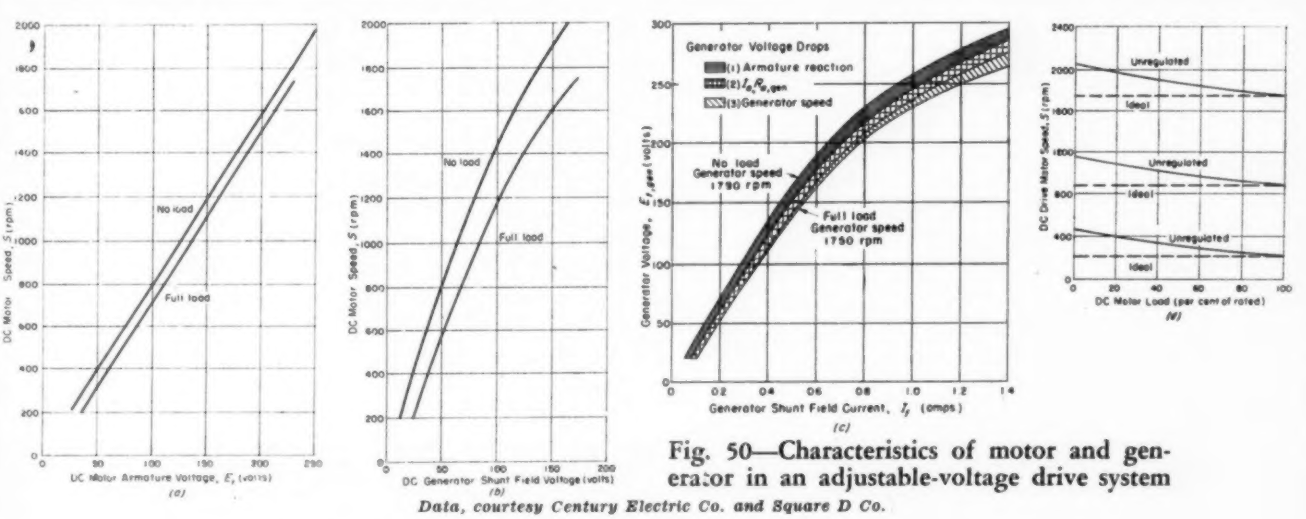
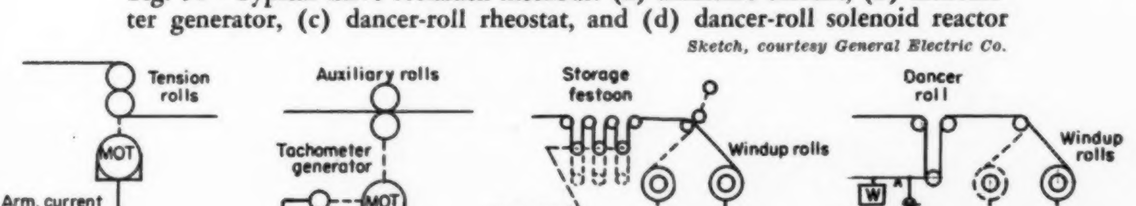


Fig. 50—Characteristics of motor and generator in an adjustable-voltage drive system

Data, courtesy Century Electric Co. and Square D Co.

Fig. 51—Typical drive feedback methods: (a) armature current, (b) tachometer generator, (c) dancer-roll rheostat, and (d) dancer-roll solenoid reactor

Sketch, courtesy General Electric Co.



than with the half-wave circuit. Self-saturating rectifiers in series with each output winding cause load current to aid in saturating the core and increase amplification by reducing control winding ampere turns.

The various amplifier-type exciters are compared in *Table* 13.

AUTOMATIC SPEED CONTROL

Motor speed can be adjusted manually, semiautomatically, or automatically to different speed settings. Also, speed can be held constant at any setting by manual, semiautomatic or automatic regulation methods. Thus, an automatic speed-control system may be required to (1) adjust speed automatically to different speeds as required throughout a process or operation and (2) regulate closely or hold any desired speed as constant as possible.

The amplifier regulators previously discussed require less power in their control devices and thus they permit a slightly higher overall drive efficiency. However, their major use is to provide fast, automatic control of motor speed. An automatic motor speed control system requires an output or regulated-quantity feedback signal and a desired reference signal. The difference between these two signals measured in terms of current, voltage, power, or frequency causes system changes that tend to make the signals identical. The reference signal may be held constant or be varied through a preset and controlled pattern.

A fast-acting amplifier type regulator is usually employed to amplify the difference between the feedback and the reference voltage signals and, in turn, to change this difference signal into a large output correction control signal.

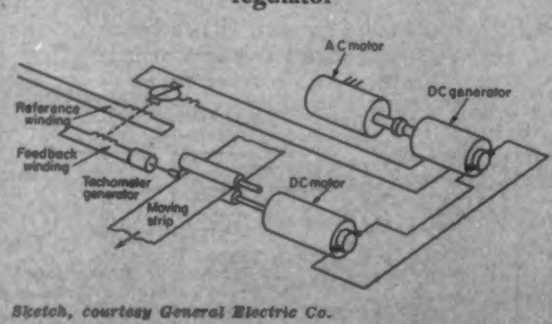
Of course, regulation as such would not be required if speed did not change once it was set. But, unfortunately, changes do arise from a number of sources.

Speed-Change Sources: Motor speed can change because of load changes and motor heating if all characteristics of motor input power are held constant. These factors cause speed changes because of variations they produce in motor circuit *IR* (voltage) drops. Thus the major reason automatic regulation of speed is required is to compensate for *IR* changes in the motor circuit. Inherent speed variation curves from no load to full load for a typical separately excited shunt motor are shown in *Fig.* 50*a*. It can be seen that in order to maintain motor speed, motor terminal voltage would have to increase slightly to compensate for increased $I_a R_a$ drop.

In a conventional unregulated adjustable-voltage drive system the dc drive-motor speed drop from no load to full load at any speed may be as much as twice the inherent speed regulation of the dc drive motor itself. This is due to a number of factors. The formula for dc motor speed in a conventional adjustable-voltage drive system is given in *Table* 14, Equation *a*. Motor terminal voltage is reduced by current I_a flowing through $R_{a,gen}$ and R_{line}. The I_a $(R_{a,gen} + R_a + R_{line})$ drop naturally varies with load and of course is highest when full load armature current is drawn.

Obviously, the proper control of E_d in *Table* 14, Equation *d*, could compensate for the *IR* voltage drop changes around the armature power circuit loop caused by load variations. Since E_d is primarily dependent on effective generator field flux ϕ_{fg} for a constant rotational speed S_g, the *IR* drop compensation could be made by increasing generator field voltage as dc drive motor load increases. The amount of generator field voltage increase required to maintain any de-

Fig. 52—Below—Adjustable-voltage drive with tachometer generator feeding a rotating regulator



Sketch, courtesy General Electric Co.

Sketch, courtesy Master Electric Co.

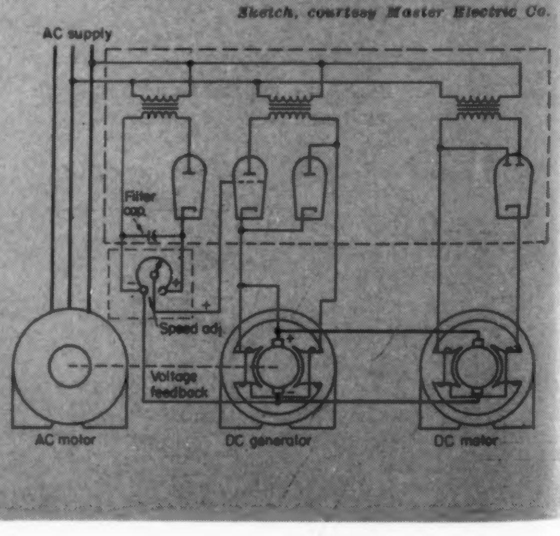


Fig. 53—Right—Simplified adjustable-voltage drive electronically excited with voltage feedback regulation

sired speed from no-load to full load in a typical adjustable-voltage drive is shown in *Fig.* 50*b*. Circuits that make up for the *IR* drop are termed *IR* drop-compensation circuits. They usually obtain an *IR* drop signal across a resistor or coil placed in series in the armature power circuit. Obviously, the greater the armature current flow, the higher the signal voltage which can be fed back to control circuits of rotating, electronic, or magnetic exciters for generator field excitation changes.

If the *IR* drops around the armature power circuit were the only factors that caused changes in dc drive motor speed, these circuits and components might be relatively easy to determine. Actually other variables enter the picture. For example, the constants K_g and K_{2m} vary somewhat with the

Table 13—Comparison of Amplifier Exciters for Adjustable-Voltage Drives

	Rotary Amplifier	Electronic Amplifier	Magnetic Amplifier
Power Source	Rotating prime mover	Ac or dc electric power	Ac electric power
Main AC Drive-Motor Size	Slightly larger than for others, to drive main generator and exciter	Same as for magnetic amplifier	Same as for electronic amplifier
Amplifier Size	Same general size as others	Same general size as others, including enclosure	Same general size as others, including enclosure
Amplifier Weight	More than electronic amplifier	Less than rotary or magnetic amplifier	About same as rotary amplifier
Effect of AC Power Variations	Practically none	Varies directly with voltage and frequency	Varies directly with voltage and frequency
Effect of AC Power Interruptions	Practically none for several seconds	Output drops to zero immediately	Output drops to zero immediately
Noise Developed	Some but usually not important	None	None
Vibration Developed	Some, but usually not important	None	None
Vibration and Shock Resistance	High	Depends on chassis and tube mounting	Extremely high
Sensitivity to Ambient Temperatures	None	Practically none	Limited only by selenium rectifier temperature ratings
Warm-up Time	None	Several seconds	None
Restarting time	None other than ac motor starting time	Several seconds with time-delay circuit	None
Output Current Characteristics	Smooth positive or negative direct current	Rectified current with ripple*	Rectified current with ripple*
Minimum Output Current	Zero	Zero	Small but finite
Field Heating Effect	Same as from any constant potential dc source	Slightly higher than constant-potential dc	Slightly higher than constant-potential dc
Voltage Polarity Reversibility	Inherently easy with one unit	None; two units are required	None; two units required
Ability to Generate and Absorb Power	Both, absorbing power aids in regenerative braking	Cannot absorb power	Cannot absorb power
Positive Cut-off of Output Power	Yes	Yes	No
Upper Limit of Output Power	None for field excitation	None	None for field-excitation applications
Lower Limit of Input Signal Power	More than a watt—ordinarily 30 or 40 watts	Practically no lower limit	Between rotary and electronic amplifier
Amplification Capabilities	High	High	High
Input-Output Circuit Isolation	Inherently good	Requires additional shielding for critical applications	Good
Input Signal Filtering	Inherently good	Requires filter for critical applications	Good
Response	Fast	Very fast	Fast†
Regulation Ability	Good	Very good	Good
Control Flexibility	High	High	High
Overall Drive Efficiency	Same general range as others	Same general range as others	Same general range as others
Operation Reliability	Very good	Good	Excellent
Initial Cost	Same general range as others	Same general range as others	Same general range as others
Maintenance Expense	Low; occasional replacement of brushes and drive belts	Low, occasional tube replacement	Very low

*Ripple factor lowest in polyphase full wave rectifiers and highest in single-phase half-wave rectifiers.

†Faster on high line frequencies such as 400 or 1000-cycle supplies.

demagnetizing effect of armature reaction in both the dc motor and the generator from no load to full load conditions. Also, if it is not a synchronous type motor, the speed of the ac motor driving the dc generator will drop in speed with increased load demand on the dc generator. These effects on generator voltage are depicted in *Fig.* 50*c*. Speed regulation curves of a typical unregulated adjustable-voltage drive are shown in *Fig.* 50*d* along with ideal regulation lines.

The adjustable-voltage speed equation also neglects brush losses found in both the dc motor and the generator. Although these losses can be considered constants for all practical purposes, they actually are not because brush losses in both the dc motor and the generator vary slightly with load, too, although the total effect is minor.

Circuitry for producing *IR* compensation is further complicated in that the compensation required is essentially a straight-line function of armature current, but must be accomplished through the control of generator field excitation which has a nonlinear relationship with generator voltage as shown by the curves in *Fig.* 50*c*. Also compensation needs to cover a wide speed range to be really effective, for armature voltage control may cover speed ranges of 8 to 1 or greater.

Feedback Signals: If control must be accurately made of speed or tension for any speed setting, feedback circuits are often employed. Feedback signals can be taken from armature current (*Fig.* 51*a*) main motor or generator terminal voltage, countervoltage, tachometer generator, ac or dc voltage, or frequency (*Fig.* 51*b*), dancer-roll control of rheostats (*Fig* 51*c*), dancer-roll control of solenoid reactors (*Fig.* 51*d*), dancer-roll control of servo motors, etc. These methods and others will be discussed in greater detail with several basic drive types.

Typical sources of feedback signals employed in adjustable-speed drives of any type are listed in *Table* 15 along with expected regulation accuracies and typical applications.

Table 14—Adjustable-Voltage Drive Speed and Voltage Formulas

$$S = K_{2m} \frac{E_t - I_a R_a}{\phi_{fm}}$$

$$= K_{2m} \frac{E_d - I_a (R_a + R_{a,\,gen} + R_{line})}{\phi_{fm}} \quad (a)$$

$$E_t = E_{t,\,gen} - I_a R_{line} \quad (b)$$

$$E_{t,\,gen} = E_d - I_a R_{a,\,gen} \quad (c)$$

$$E_d = K_g S_g \phi_{fg} \quad (d)$$

Regulator Applications: Any regulating system first compares the regulated quantity—voltage, current, speed, tension, etc., against a fixed reference. It then amplifies the difference or error between the two and corrects the regulated quantity so as to reduce the error between the two. Rotating and magnetic amplifier regulators employ independent control windings to modify excitation output characteristics. Similarly electronic amplifier regulators use grid phase-shift control to regulate output.

In rotary or magnetic amplifier control usually three or four field windings are provided. In actual applications one field may be electrically connected to a tachometer generator on the main dc drive motor and another field may be connected to a supply of constant reference voltage *Fig.* 52. The first field is the feedback speed-control field and the second is the reference voltage control field. Usually the speed field and reference field are adjusted by variable resistors so as to cancel each other at the normal or desired speed of operation, and the regulating exciter voltage output comes solely from flux set up in the self-energized field. Should drive motor speed change due to load changes and other causes, the tachometer generator output will change the speed field current. This condition will create an unbalance between the speed control field and the reference

Table 15—Common Feedback Methods

	Electrical Feedback Signal Source			
	Main Generator or Motor Voltage	Motor Counter Voltage	Pilot-Generator Voltage	Tachometer Frequency
Approximate Accuracy at Top Speed (per cent)	±3.0	±1.0	±0.5	±0.1
Typical Drive Applications	Hoists; blooming, slabbing, and plate mill (main and auxiliary drives); bulk unloaders	Machine tools, elevators, hoists, winders, calenders, electric shovels, tandem cold-reduction mill, high-speed steel-mill reels	Paper-making machines, wind tunnels, dynamometers, rubber and plastic calenders, cellophane and runner extruders, tire-testing machines, rod and merchant mills, flying shears, slitting lines	Paper-making machines, man-made fibre spinning machines

Data, courtesy Westinghouse Electric Corp.

voltage field, resulting in flux that will immediately either increase or decrease exciter voltage output, and either raise or lower dc drive motor speed to restore it to its desired value. Thus, this is an automatic speed regulating system. To adjust or vary motor speed deliberately at any time, all that is necessary is to change the reference voltage by rheostat control.

In the voltage regulator, *Fig.* 49, the dc reference voltage winding serves as the standard of comparison. The feedback control winding measures generator voltage and is connected so as to oppose the reference voltage. A small difference in the strength of these windings will saturate the magnetic cores causing corrective current to flow through the generator field, thereby causing its voltage to match the reference voltage within close limits. To match the regulated quantity as closely as possible to the reference and to remove

quickly any load disturbance, a fast acting regulator with high amplification is needed.

A motor-generator drive with voltage feedback control to an electronic amplifier exciter is shown in *Fig.* 53.

Many other methods of regulation are possible besides voltage regulation. In *Fig.* 54 are shown three more basic forms of current and voltage feedback circuits. Current feedback is more closely associated with motor torque.

A basic magnetic amplifier drive circuit is shown in *Fig.* 55 with an antihunt winding and an IR

Fig. 54—Adjustable-voltage drive feedback circuits for regulation from (a) current, (b) current and voltage (countervoltage), and (c) voltage with current limit

Sketch, courtesy Century Electric Co. and Square D Co.

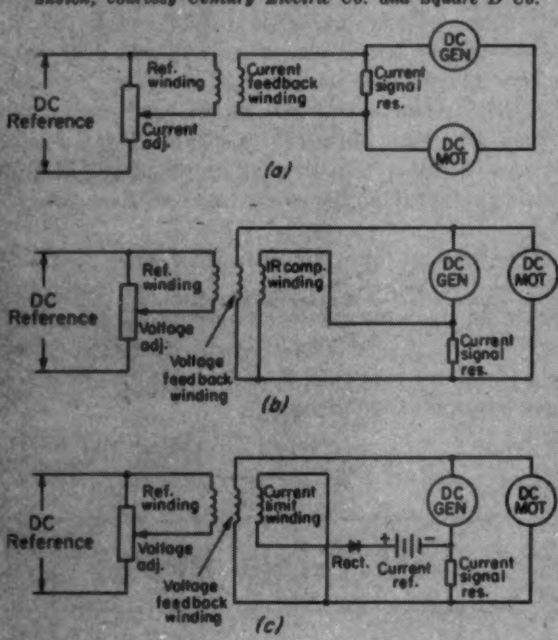
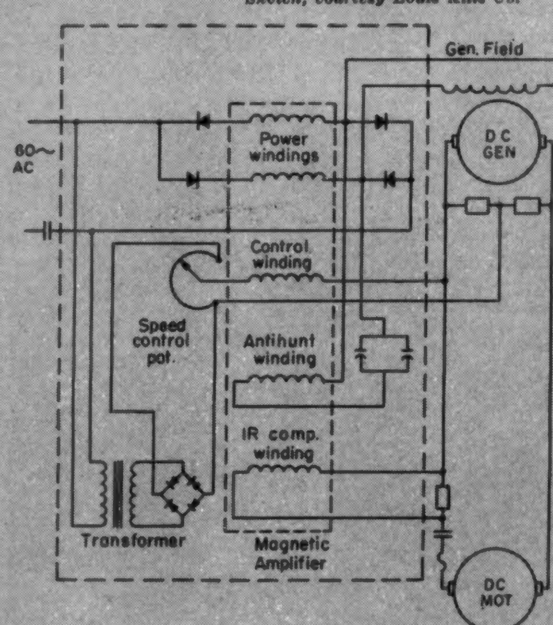


Fig. 55—Magnetic amplifier exciter control of generator field excitation

Sketch, courtesy Louis Allis Co.



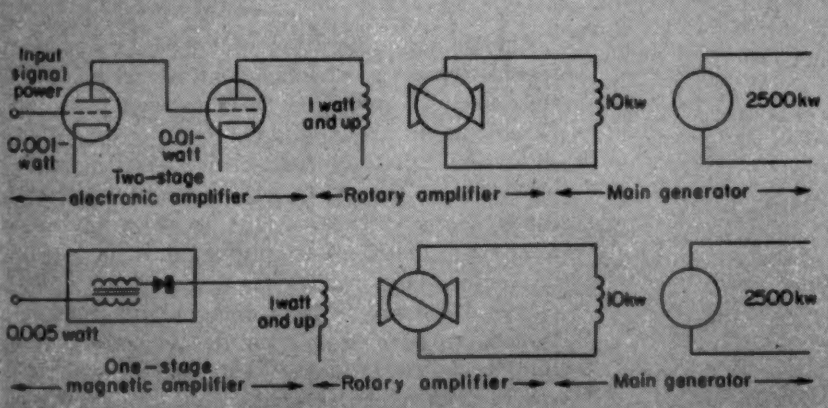
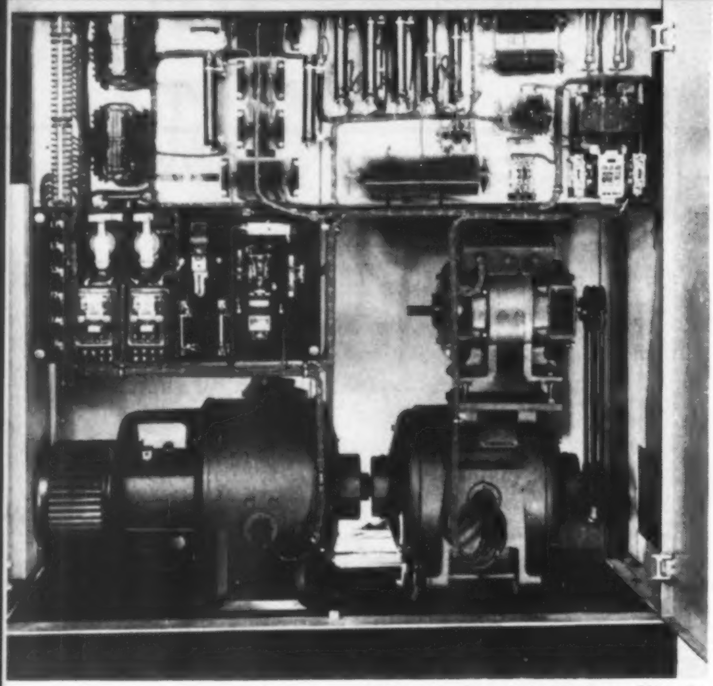


Fig. 56—Combination rotary-electronic amplifier exciter system and combination rotary-magnetic amplifier exciter system with possible power levels

Data, courtesy General Electric Co.

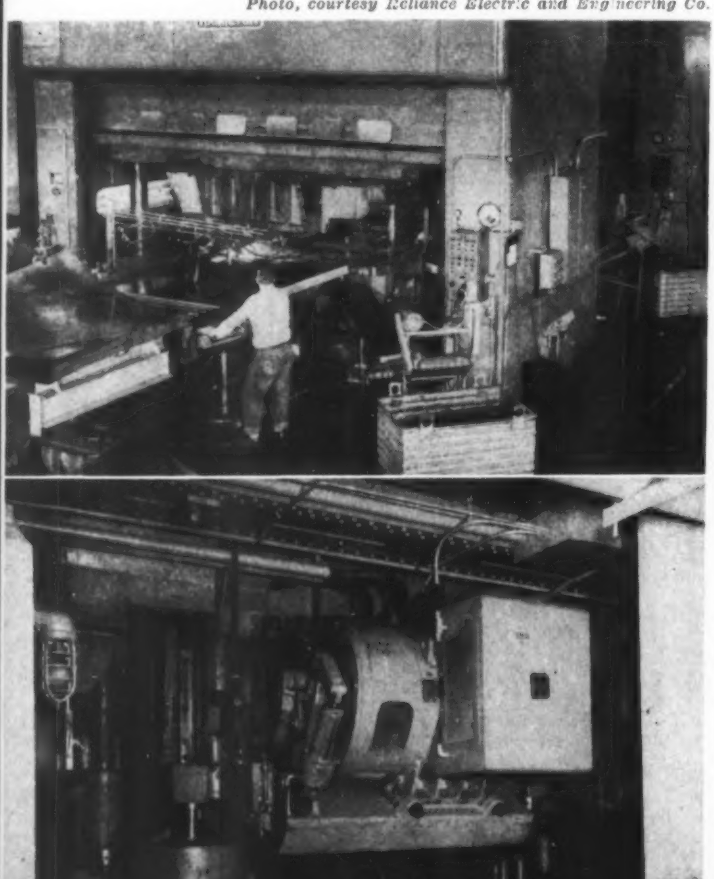


Photo, courtesy Allis-Chalmers Mfg. Co.

Fig. 57—Above—Packaged drive power unit for 15-hp reversing drive with a combination magnetic amplifier and rotary amplifier excitation control

Fig. 58—Below—Adjustable-speed 500-hp drive for automobile body press obtains fast-acting forcing torque by a combination electronic and rotary field exciter

Photo, courtesy Reliance Electric and Engineering Co.



drop compensation winding.

Magnetic amplifiers and electronic amplifiers may be used in combination with rotary amplifiers to give greater sensitivity and flexibility of control, *Fig.* 56. A magnetic amplifier-rotary amplifier combination packaged drive power unit is shown in *Fig.* 57. A combination of an electronic amplifier and rotary amplifier excitation control is used in the huge press in *Fig.* 58.

RECTIFIER DRIVES

In the selection of adjustable-speed drives, the pros and cons of the different systems require careful comparison. The strong points of the adjustable-voltage motor-generator drives already discussed include unlimited horsepower sizes, reversing service, regenerative braking, and machine protection during momentary power failures.

Rectifier drives, on the other hand, provide the following relative advantages: (1) less weight and smaller size per unit of output, (2) less noise and vibration, (3) higher overall efficiency, (4) somewhat lower initial and maintenance cost in low-power ranges, (5) wider speed ranges.

Such drives have two principal forms: electronic rectifiers and metallic rectifiers. In electronic drives, output is controlled by adjustment of grid voltage relationships of a number of possible tube types.

The power input or output of metallic rectifier drives are controlled by adjustable resistors, adjustable transformers, or controllable saturable reactors (magnetic amplifiers). Rectifier types include copper sulphide, copper oxide, selenium oxide, germanium, and silicon.

ELECTRONIC DRIVES

The general operation and function of all-electronic drives is almost identical with electronic field exciters employed in motor-generator drives. Electronic drives usually employ vacuum tubes and thyratron tubes for field circuit control, and they use vacuum, thyratron, excitron, and ignitron type tubes for armature circuit input power control. Electronic rectifiers supply constant or adjustable dc motor field excitation as in motor-generator drives. However, instead of supplying field excitation to an ac motor-driven dc generator, which in turn provides dc motor armature power, the electronic drive rectifies single phase or polyphase ac and supplies armature power directly. The power

input to the armature circuit is controlled by the amount and nature of the bias voltage on the grids of the electronic rectifier tubes.

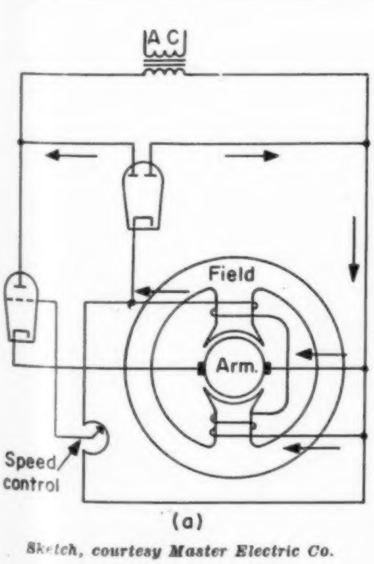
Shunt vs. Series Motors: In electronic drives employing shunt motors the regulation is often achieved by the use of the generated armature voltage (countervoltage) as a speed signal. In addition, some form of *IR* compensation is often used to advance the thyratron firing angle to compensate for load changes as indicated by an increase in armature current caused by increased load. Many circuits use these speed regulation principles to achieve excellent stability of motor speed with load changes from no load to full load, without the expense of tachometer feedback. Some manufacturers of this type of drive claim speed regulation of 2 per cent or even less. However, speed regulation ratings do not include speed change as a function of either motor terminal voltage or motor temperature. The armature countervoltage method is only an accurate indication of speed when the magnetic flux from the field is constant. In the case of the dc shunt-field motor, field current decreases with increased resistance caused by motor temperature rise. Therefore, most such drives gradually increase speed during the first several hours operation unless pilot generators, tachometer frequency, or dancer-roll rheostats are employed as feedback.

Since the shunt field is usually supplied with a dc voltage obtained from a separate line voltage rectifier, speed also varies with changes in supply voltage. Of course, the shunt motor has much better inherent regulation characteristics.

All electronic drives using grid-controlled rectifiers have a common problem with motor temperature rise at low speed. These drives achieve low speed by applying power to the motor intermittently. Since wattage varies as the square of the current, a dc motor powered by an electronic drive will have a somewhat higher operating temperature than if supplied by the same power with a continuous constant-value current. Most motors incorporate an internal cooling fan, but fan output decreases to a negligible value at low speeds.

Thus, it is usual practice with electronic drives to use the next larger frame size. This applies to motors of either the shunt or series type. However, some manufacturers claim the series motor does not heat up as much as shunt motors, particularly in half-wave circuits. One reason given is that the series-motor field is only energized for a half-cycle and at a current proportionate to load.

Thyratron Types: *Fig.* 59*a* shows a basic electronic drive employing a half-wave armature circuit with a grid-controlled thyratron tube. An essentially constant potential is supplied to the field circuit by a dual-diode rectifier tube. The polarity motor field countervoltage causes the right half



Sketch, courtesy Master Electric Co.

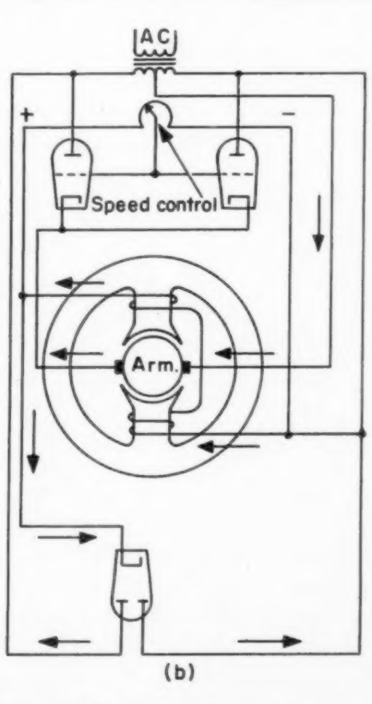


Fig. 59 — Basic half-wave electronic drive, *a*, and full-wave electronic drive, *b*

Photo, courtesy Charles Bruning Co. Inc.

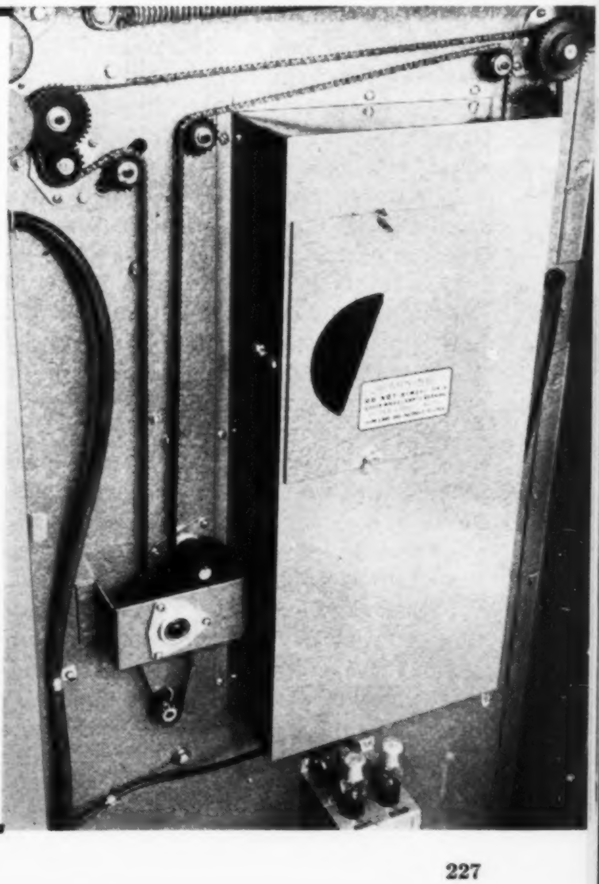
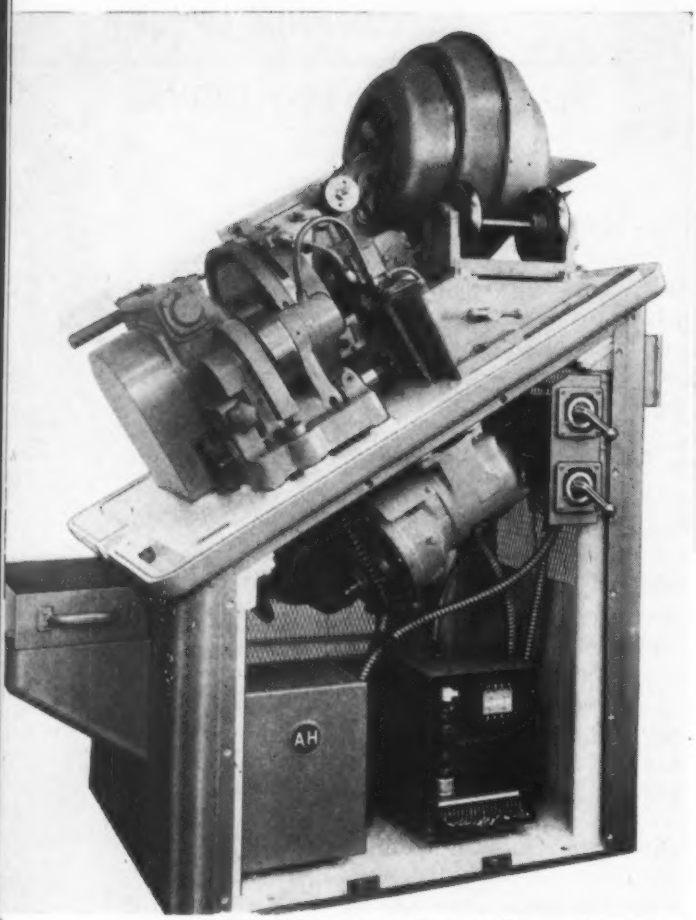


Fig. 60—Right—Photocopy machine employing a Gerald K. Heller Co. electronic dc series motor drive



Photo, courtesy Arrow-Hart and Hegeman Electric Co.

Fig. 61 — Centerless grinder employing a dc series motor electronically powered

Photo, courtesy Industrial Control Corp.

Fig. 62—Electronic drive with built-in speed indicator for an Electric Indicator Co. series motor

of the diode rectifier to conduct during the negative portion of the input voltage cycle. Thus, the current waveform through the motor field is rather smooth. By employing this circuit, a center-tapped transformer is eliminated but, of course, field circuit voltage is not adjustable.

A basic electronic drive using a full-wave armature-circuit rectifier with grid controlled electronic tubes is shown in *Fig.* 59*b*. Here a center-tapped transformer is required. The field circuit is excited in the same manner as outlined for the half wave circuit in *Fig.* 59*a*.

One of the smallest electronic drives commercially available is shown in *Fig.* 1. Employing a permanent-magnet motor, the circuit does not require a field excitation supply. Armature current is controlled with a single miniature electronic tube. Some of the simplest small electronic drives employ series motors. These adjustable-speed drives are quite suitable for low-power constant-torque applications, *Fig.* 60. A somewhat larger application of an adjustable-speed series motor type electronic drive is shown in *Fig.* 61. Small electronic drives may employ series type motors *Fig.* 62, and have 100 to 1 speeds with typical ranges of 50 to 5000 or 100 to 10,000 being commercially available. The control unit in *Fig.* 62 has a calibrated speed indicator built into the control box.

By employing circuits with a separately excited "series" motor field, an extremely closely regulated reference voltage, and a tachometer generator feedback, speed regulation is extremely low and there is practically no speed drift. Such an electronic drive employing a separately excited "series" motor, *Fig.* 63, has a speed regulation of 0.125 per cent.

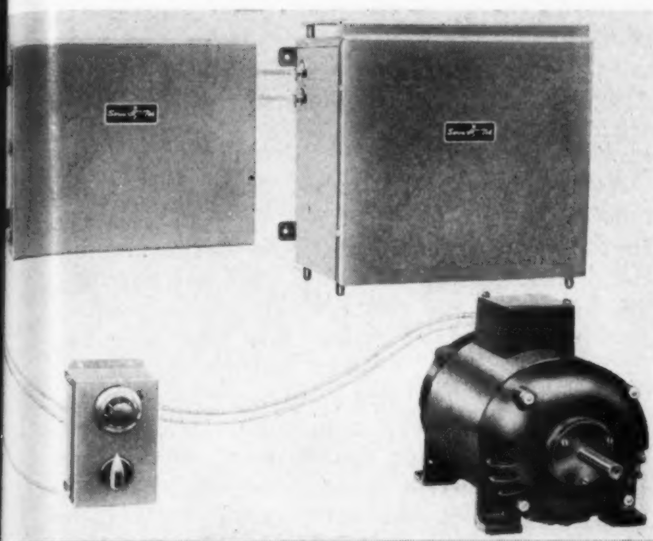
Electronic drives are particularly suitable for continuous-process applications requiring constant tension or torque and constant speed for any desired speed setting.

A basic pictorial representation of equipment location of an electronic drive with tachometer feedback for speed control is shown in *Fig.* 64*a*.

For constant-tension or torque applications, dancer-roll rheostats and feedback-position servos are widely applied, *Fig.* 64*b*. Another typical application where an electronic drive is used to maintain constant tension is shown in *Fig.* 65. Here tension controls plastic pipe diameter in an extrusion machine.

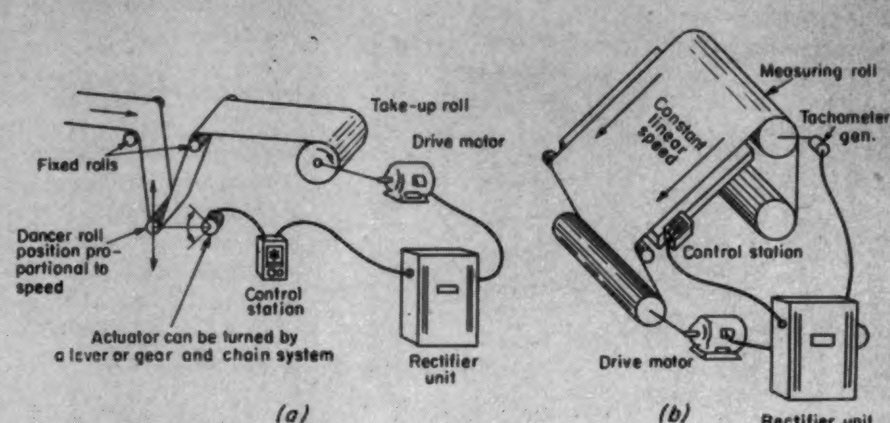
As speed range increases, control requirements and horsepower capacity increase; electronic drives of necessity become more elaborate, larger and heavier. As speed range increases, both armature and field control are required. Electronic drives have been developed that can provide speed ranges as wide as 240 to 1. A basic pictorial diagram circuit of a shunt-motor electronic drive with both a grid-controlled field supply and armature supply is shown in *Fig.* 66. The armature is depicted with heavier lines to indicate the heavy current circuit. The control station is shown with two speed control pointers. One is for armature circuit speed control and the other is for field circuit. The time delay relay (marked TD) prevents power from being drawn from the tubes until the filaments of vacuum or thyratron type tubes are hot enough to emit electrons easily, thus aiding long tube life.

The anode transformer for the tube plate voltage in electronic drives may be incorporated inside the ac power conversion and control unit or it may be brought out as a separate unit, *Fig*. 67. The anode transformer is sometimes external for cooling and to minimize heat in the power unit. The operator control station, ac power unit, and anode transformer can be built into machines at appropriate locations or installed on walls or other supports.



Photo, courtesy Servo-Tek Products Inc.

Fig. 63—Above—Separately excited "series" motor fractional hp electronic drive with 100 to 1 speed range less than 1 per cent and speed regulation



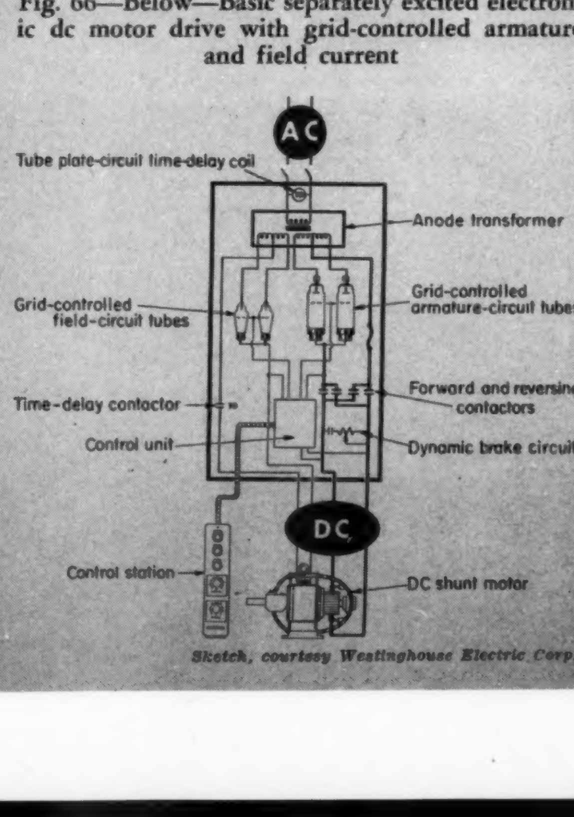
Sketches, courtesy Servospeed Div., Electro Devices Inc.

Fig. 64—Right — Automatic tension control, *a,* and speed control, *b,* of electronic drives

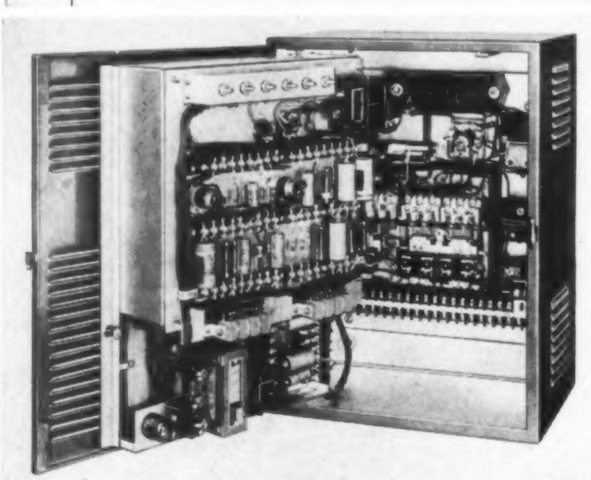
Photo, courtesy Servospeed Div., Electro Devices Inc.

Fig. 65—Left—Electronic ¾-hp shunt-motor drive for plastic-pipe extruder made by Progressive Machine Co. Inc.

Fig. 66—Below—Basic separately excited electronic dc motor drive with grid-controlled armature and field current



Sketch, courtesy Westinghouse Electric Corp.



Photo, courtesy Louis Allis Co.

Fig. 67—Above—Electronic drive with armature reversing, dynamic braking, stability control, and a single knob speed adjustment

Fig. 68 — Below — Electronic excitron tube drive power unit, left, and application showing drive power unit mounted high above the floor, right

Photo, courtesy Reliance Electric & Engineering Co.

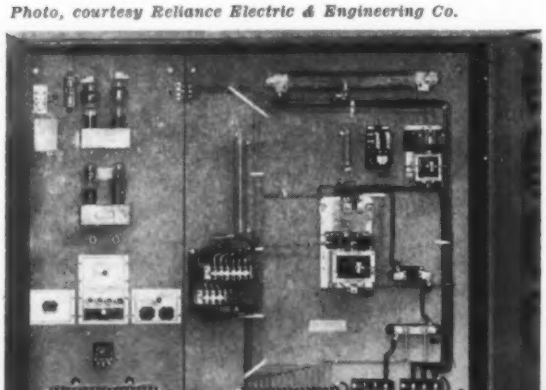
Overall thyratron electronic drive efficiency in the low-horsepower range (1 to 25) is often 10 to 15 per cent greater than motor-generator drives. Electronic drives with mercury-pool rectifier tubes are also more efficient than motor-generator drives.

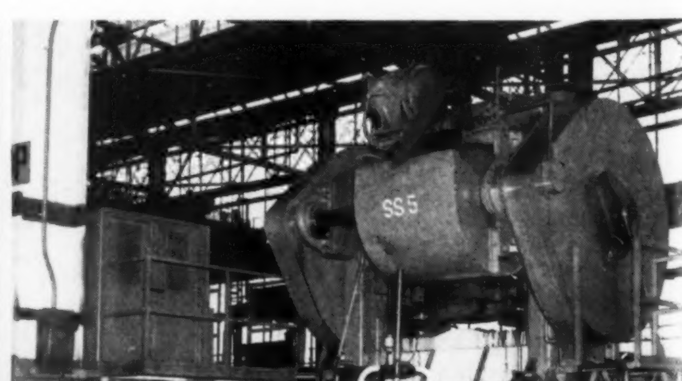
Excitron Types: The newly developed excitron tube drives have made possible electronic drives in the 25 to 50-hp range that are comparable in initial cost to motor-generator drives. Built as a packaged drive, *Fig.* 68, the power conversion unit circuit employs six excitron mercury pool tubes operating on three-phase ac. A 50-hp excitron control unit weighs only 1250 pounds and is only about ¼ the size of a typical 50-hp motor-generator drive control unit which weighs approximately 6000 pounds. The great reduction in size and weight permits such large-horsepower drive-control units to be placed in out-of-the-way locations, *Fig.* 68. These drives will eventually be built in output power sizes above 50 hp.

Ignitron Types: Drives employing ignitron tubes are often used to operate motors of 200 hp and up. In comparison to motor-generator sets, these ac-to-dc power-conversion units offer advantages of higher efficiency (*Fig.* 69), quiet operation, high momentary overload capacity, and lower maintenance. In addition they require no special foundation or ventilation. These units are most commonly used to supply 250-volt dc power for rolling mill drives and auxiliaries.

MAGNETIC-AMPLIFIER DRIVES

Like all electronic drives, magnetic-amplifier drives can operate dc motors directly from ac lines





with no ac motor-dc generator set required. The outstanding advantages claimed for magnetic amplifier drives are simplicity of circuit components, freedom from maintenance, and high reliability.

Circuit components are inherently rugged because they are made almost entirely from various forms of metal and insulation material. In addition there are no moving parts, other than speed controls, contactors, start-stop buttons and the like. With no high-velocity rotating parts in the control units, vibration is minimal. These factors result in an ac-to-dc conversion and speed-control unit that is not only rugged in normal environments but one that is highly resistant to shock and vibration. The metallic rectifiers are about the only components that can ordinarily fail, and then only if upper temperature ratings—usually 100 F—are exceeded. Thermal overload devices are usually included to protect both the rectifiers and the motor against damaging temperature rises. Developments in rectifiers promise higher temperature ratings in the near future.

Of course, as with all drives there are drawbacks. For example, the magnetic amplifier shares with the electronic amplifier the irreversible characteristics of the rectifier, whether metallic or vacuum tube. Reversible drives are possible but they are usually large, bulky and more complicated in large horsepower ratings. Thus, service requiring reversing operation is usually avoided with either of these drives. For such service the conventional adjustable-voltage motor-generator drives with rotating exciters are preferred. Also regenerative braking—helpful for fast reversals—is not ordinarily possible with magnetic-amplifier or electronic drives.

The magnetic-amplifier drive can only approach the electronic drive in speed of response, but in both response is exceedingly fast. On the other hand, input signals for regulation purposes in the magnetic amplifier can be completely isolated. Because of this, magnetic amplifiers can be connected in series.

Commercially available horsepower ratings in magnetic-amplifier drives extend from 1/40 to 5 horsepower. Drives with higher horsepower ratings are certainly possible but they become rather heavy and bulky. Also, compared with electronic drives, they are at a disadvantage on an initial cost basis much above ¼ to ½-hp.

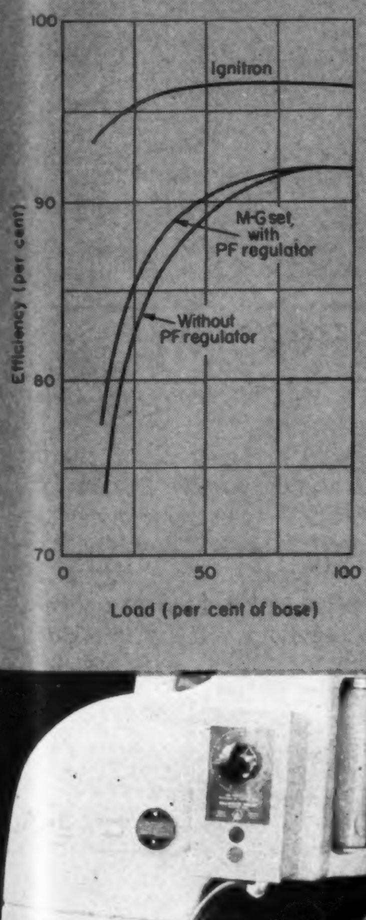
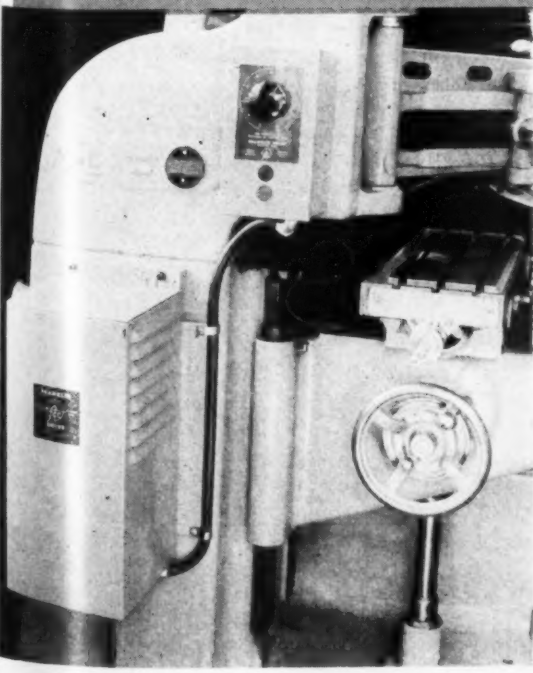


Fig. 69—Comparison of efficiency of a 15,000-kw, 700-volt ignitron rectifier and motor-generator drive

Data, courtesy Westinghouse Electric Corp.



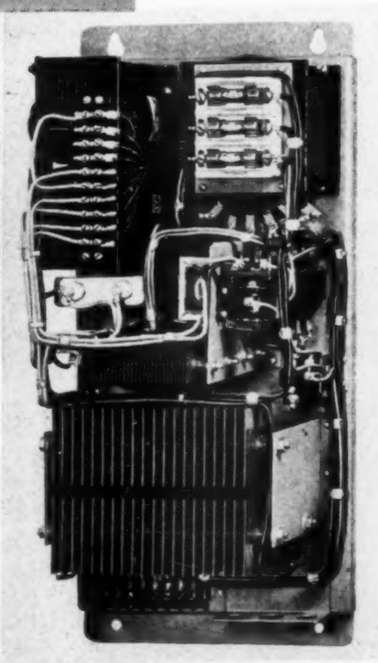
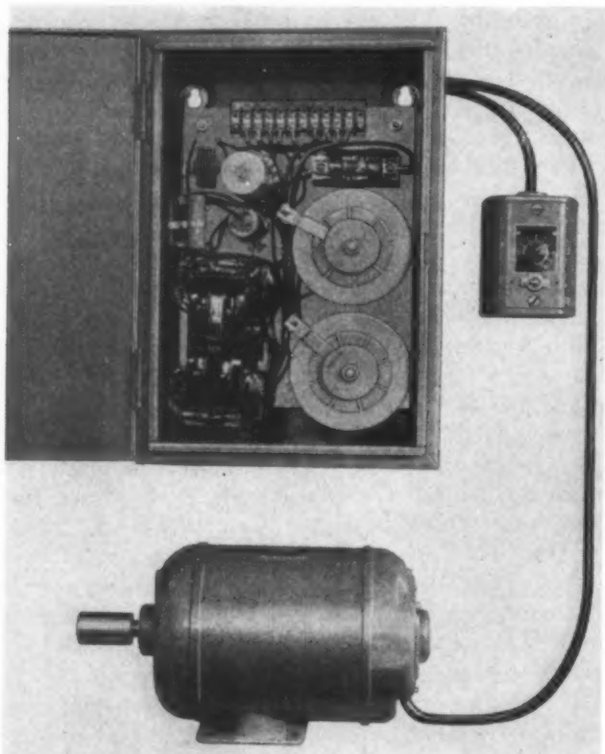


Fig. 70—George Gorton Machine Co. pantograph engraver with ½-hp magnetic-amplifier drive. Combined with stepped pulleys, drive provides 500 to 12,000-rpm speed range

Photo, courtesy Franklin Control Corp.

For the drive shown in *Fig.* 70, speed ranges of 100 to 1 are available. Magnetic amplifier voltage to armature is controlled by a bias voltage, reference voltage, armature voltage, and armature current to regulate motor speed and torque. Speed settings are made with an adjustable transformer.

A simpler magnetic-amplifier drive with rheostat speed adjustment is shown in *Fig.* 71. This drive has preset jog, dynamic braking and reversible rotation as optional features.



Photo, courtesy Clark Controller Co.

Fig. 71—Simplified magnetic-amplifier drive available in 1/40 to 1/2-hp range

ADJ. TRANSFORMER DRIVES

Relatively low in cost and small in size, adjustable-transformer drives are finding wide application. They employ electronic or dry-plate metallic rectifiers—usually the latter—to obtain ac rectification. Field voltage is usually held constant on separately excited dc motors. Motor speed is controlled by adjusting an autotransformer supplying ac power to a dry-plate metallic rectifier. The rectifier output voltage is applied across the motor armature.

A typical circuit is shown in *Fig.* 72. The adjustable transformer may be incorporated with the rectifier unit, *Fig.* 72, or placed elsewhere.

Such drives are made in a wide range of horsepower sizes for series, shunt or compound motors. They find wide application in machines where speed regulation is relatively unimportant.

SEMICONDUCTOR DRIVES

Developments are rapidly bringing attention to germanium and silicon semiconductors for many new uses. Applications for semiconductors will undoubtedly spread to adjustable-speed drives. At least one company lists a transistor input magnetic amplifier today. Germanium rectifiers have a number of advantages over selenium and copper oxide

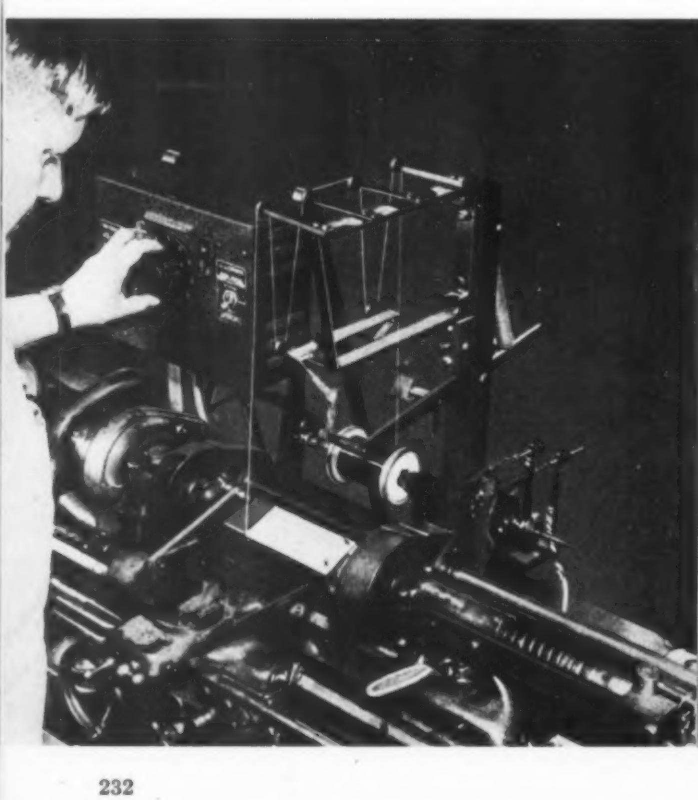
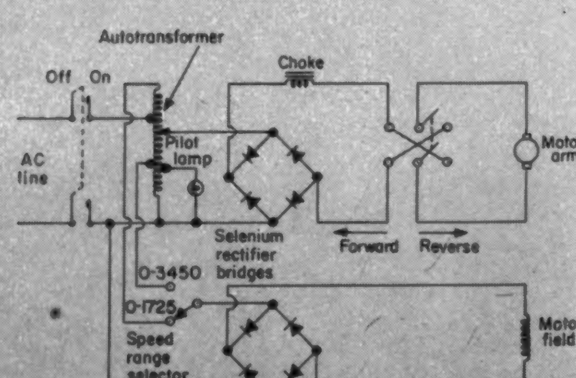


Fig. 72—Typical adjustable-transformer drive circuit and an application on a resistance-card winding machine

Photo, courtesy General Radio Co.



units. These include: (1) longer life, (2) higher efficiency (3) higher cell ratings (4) lower losses and (5) smaller cell size. The chief drawback today is cost and availability of germanium.

Silicon rectifiers operate at higher temperatures and reduced back current, but problems inherent in their production are the principal deterrents to their use. Silicon's greater sensitivity to temperature changes and its forward resistance are sufficient to limit its adoption to certain applications. Rectifier development appears to lie in the field of compound semiconductors utilizing two or more elements.

SPEED ADJUSTMENT OF AC-DC MOTORS

One of the most common motors used on single-phase alternating-current power for low-horsepower adjustable-speed applications is the universal motor. Although designed for operation on either ac or dc and at any frequency up to 60 cycles, the motor usually is used on 60-cycle alternating-current power. These motors have been manufactured in sizes up to about 3 hp, but are usually restricted to fractional horsepower sizes from ⅓-hp down, with motors as small as 1/1500-horsepower being available. Universal motors are designed with laminated armatures and field poles in order to operate essentially the same on either dc or ac. That is, speed and power output on a particular dc voltage will be approximately the same on the same rms (root mean square) ac voltage. Actually, the motors run slower on direct current because of the factor of inductance.

For most applications of universal motors, loads are more or less constant or variations in speed with load are unimportant. Typical adjustable-speed applications include portable drills, vacuum cleaners, sewing machines, small movie projectors, and food mixers.

There are two major classifications of universal motors: noncompensated and compensated. The compensated types have an additional field winding in series with the regular series windings. The compensating winding is so arranged as to (1) reduce reactance voltage when the motor is operating on alternating current, (2) reduce field distortion, and (3) improve commutation. All of these improvements tend to increase speed and power. Thus, the compensated motors have higher speed-torque curves for ac operation and give nearly identical performance for ac and dc service.

As with dc series motors connected to a constant voltage source, speed can be adjusted by employing adjustable resistors. The universal motor can be reversed by simply reversing the relationship of the fields with the armature. Of course, the brushes must be physically centered between the poles to provide nearly equal operating characteristics in both directions. Thus, a reversible type motor must be specified if satisfactory reversing service is desired.

Adjustable resistors, *Fig.* 73, are often used with universal motors on electric sewing machines.

A method of speed adjustment that is more efficient than variable resistors is to utilize an autotransformer. This eliminates heat radiation from resistors, sometimes a problem. Actually this

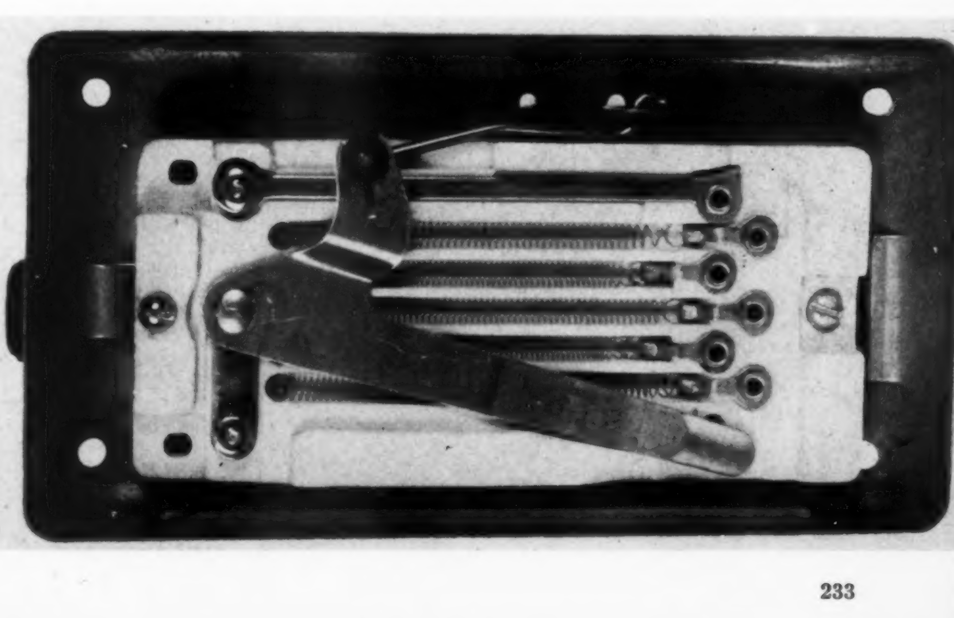


Fig. 73 — Nichrome-wire stepped-resistor speed control for small motors

Photo, courtesy Electrical Mfg. Co.

is an adjustable-voltage method. Tapped transformers may also be used.

There are specially designed universal motors which have tapped field windings. Different speeds are obtained with a selector switch.

At least one portable electric mixer, *Fig.* 3, obtains two speeds by using a universal motor with two windings. An off-low-high switch connects either one winding or the other.

All dc and universal motors can be adjusted in speed by mechanically moving the brushes with respect to the field poles. However, this method is seldom employed except with universal motors because of heavy arcing at low speeds. The arcing is caused by the brushes being so far from a neutral position at low speeds. Although the method tends to pit the armature, little trouble is encountered within short and infrequent operating periods at low loads.

Electric Centrifugal Governors: Speed of small dc series, shunt and universal motors and ac repulsion motors in the range of 1/100 to ½-hp can be rather closely regulated with electric centrifugally-operated speed governors. Electric governors are most commonly used to regulate the speed of universal motors in such applications as movie cameras and projectors, desk calculators, electric typewriters, oxyacetylene cutting machines, and electric drills, *Fig.* 74. A governor-controlled universal motor performs almost exactly the same on alternating current or direct current.

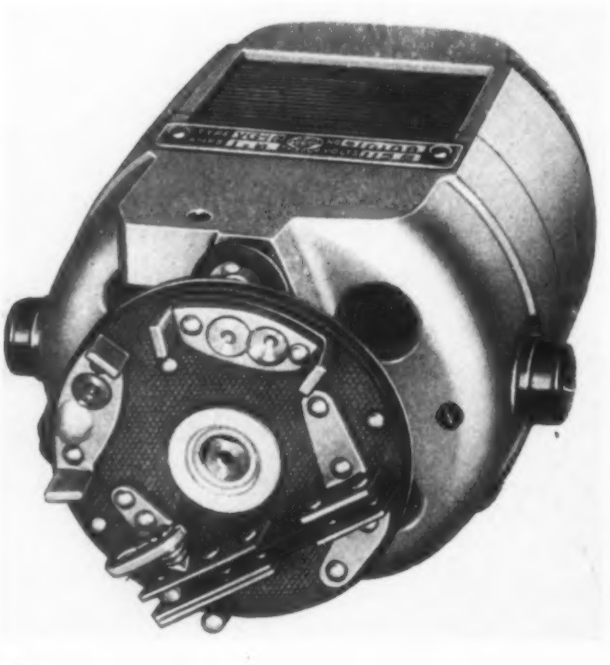
Centrifugal governors can usually be manually adjusted to provide a wide range of preset speeds. Some units are designed for screwdriver adjustment while the governor motor is stationary and are available for one speed control, *Fig.* 75, and two-speed control. Speed governors are also designed to permit stepless adjustment to any speed while the motor is running, *Fig.* 75, by means of threaded knobs or lever arrangements, *Fig.* 74. These screw, knob or lever adjustments change the position of a stationary contact with respect to a movable contact. This, in turn, controls the speed at which the contacts will open from centrifugal force.

The governor contact assembly is mounted on the end of the motor shaft. The vibrating contacts are wired to slip rings. Stationary brushes connect the contacts in the motor circuit and the paralleling contact resistor and capacitor.

In controlling the speed of a series or universal motor, the contacts are closed until the motor reaches a preset speed. At that point the contacts open by means of centrifugal force and resistance is inserted in series with motor armature and field coils. This reduces armature current

Photo, courtesy Electro-Mechano Co.

Fig. 74—Above—High-speed precision drill press with manual adjustable-governor speed control. Typical speeds are 1000 to 10,000 or 2500 to 15,000 rpm



Photo, courtesy Bodine Electric Co.

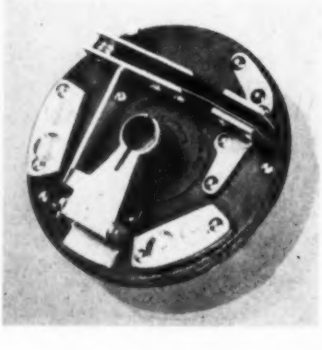


Fig. 75—Left — Lee Engineering Co. centrifugal speed governor mounted on motor, left, at standstill, speed adjustment can be made with screw driver. For governor at right, speed can be adjusted with knob or lever while motor is running

which reduces motor speed, and the contacts close again. Reclosing of the contacts causes the motor to accelerate again. Since the interruption frequency may range from 200 to 600 cycles per second or more depending on the governor speed setting and motor load, actual operating speed remains at almost a constant value for any given setting. Of course, the governor can only hold speed from no load to the normal torque capacity of the motor for any preset speed. In general, the smaller the load, the faster the contacts vibrate.

For universal motors, speed ranges are usually limited to 10 to 1 or 12 to 1. Typical speed ranges possible are 500 to 6000, 1000 to 10,000, 2500 to 15,000 etc. Over such wide ranges, speed can vary as much as $\pm$ 10 per cent at some settings. If the range is more limited such as 4 to 1, speed can be maintained within limits of $\pm$ 2 to 4 per cent at any particular setting. In general, best operation is obtained over a speed range of 2000 to 6000 rpm.

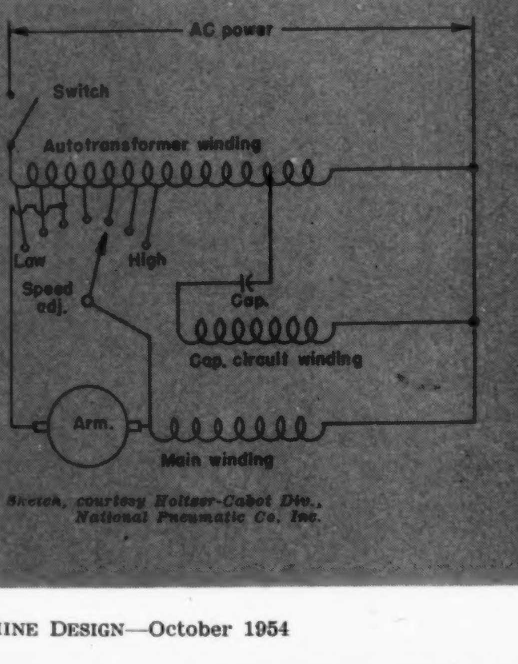
Electric governors for shunt motors are placed in the field circuit and are normally open. These units, used in shunt motors, can only hold preset speeds from base speed up because it is a field weaking method. Where a governor is used on direct current only, such as a shunt motor, a split slip-ring type of governor is required to supply alternating current to the contacts. This prevents polarization of contacts and consequent roughening with eventual sticking.

SPEED ADJUSTMENT OF A-C MOTORS

The ac motor is usually considered to be a constant-speed rotating machine. The only exceptions are the ac commutator type motors such as the ac series motor or repulsion type motors. Because of the constant-speed characteristics of other ac motors and also the fact that ac power is so prevalent, these motors find wide application in industry.

Equation 8 in *Table* 1 shows that ac motor torque is proportional to the square of terminal voltage. Speed of an ac motor depends on line frequency, number of poles in motor, and slip, as shown in *Table* 1, Equation 9. The formula for slip is given in Equation 10 of *Table* 1. Speed can also be controlled by voltage reduction which increases slip. Of course, synchronous motors have no slip.

Fig. 76 — Basic connection diagram for fractional-horsepower shunt-type ac motor



Sketch, courtesy Holtzer-Cabot Div., National Pneumatic Co. Inc.

SERIES MOTORS

Alternating-current series motors can be adjusted in speed by varying voltage across the field and armature with adjustable resistors by the methods shown in *Table* 2 for dc series motors. Ac motor speed can also be controlled by adjustable autotransformers, tapped transformers, motor centrifugal governors, and brush shifting.

Fig. 77—Single-phase repulsion motor with brush-shifting speed adjustment

Photo, courtesy Star-Kimble Motor Div., Miehle Printing Press and Mfg. Co.

Large high-voltage ac series motors are used chiefly in railroad traction, crane and hoist applications. The universal motor is the most common ac series motor and its characteristics have been covered in the previous section.

SHUNT MOTORS

Shunt-wound commutator motors do not ordinarily operate on ac due to a phase shift of about 90 degrees between the shunt field, which is highly inductive, and the armature circuit, which has little inductance. With this phase shift there can be practically no torque developed. One method that has been employed to overcome this factor is shown in *Fig.* 76. In this circuit design, the shunt type motor operates on ac by virtue of a resonant circuit which provides nearly unity power factor in the shunt field.

REPULSION MOTORS

Speed of repulsion motors can be controlled by increasing slip with series resistors, *Table* 12, or reactors in the motor input circuit. Also, adjustable transformers can be employed to control motor speed. In general, a 2 to 1 speed range would be a normal practical limit. In all methods the motor is more sensitive to changes in load, the lower the speed.

Repulsion motors can also be adjusted in speed by mechanically shifting the brushes from a normal optimum operating position. The speed characteristic of a repulsion motor is similar to that of a series ac motor. However, at exceptionally light loads, the speed does not become as high as would be expected of a series ac motor. Since optimum performance of a repulsion motor is secured by proper location of the brushes with respect to the center line of the stator poles, reduced speed can be secured by shifting the brushes in the direction of rotation. By placing the brushes on a rigging which can be rotated smoothly and steplessly from one position to another, stepless speed adjustment can be provided.

The speed characteristic of a repulsion motor is somewhat unstable, because it varies inversely with torque. Speed variations that accompany changes in load can be corrected manually by shifting the brushes.

Adjustable-speed motors of this type are equipped to mechanically shift brush position by a handle which can be operated manually, *Fig.* 77.

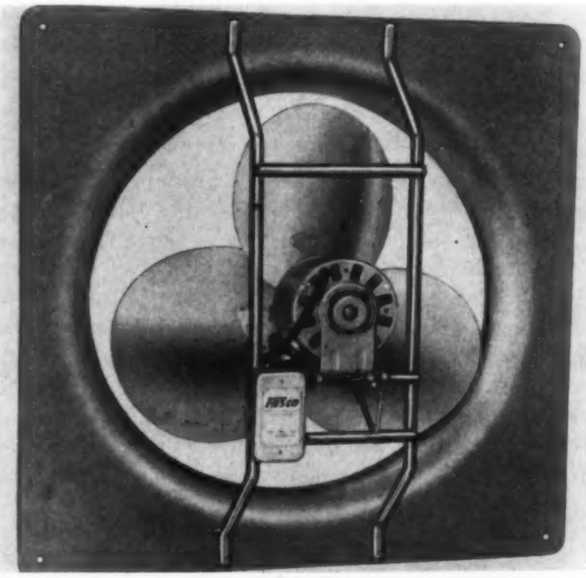
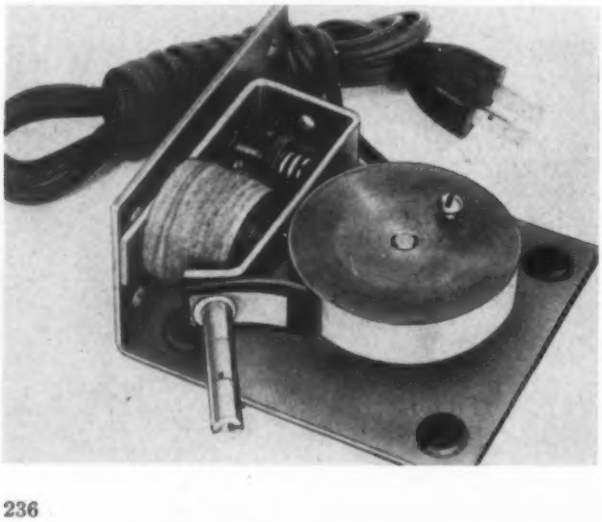


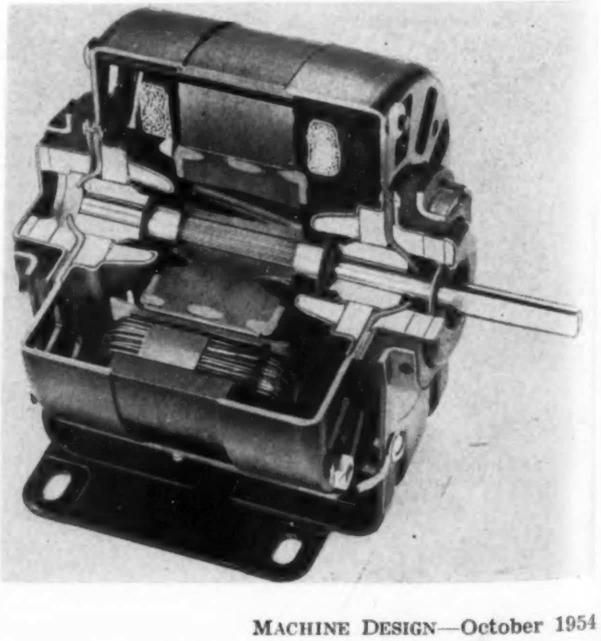
Fig. 79 — Fractional-horsepower shaded-pole motor and typical fan application

Photo, courtesy Fasco Industries Inc.

Fig. 78 — Small ac impulse motor, 2 by 4 by $5\frac{1}{4}$ in., adjustable in speed from 1 to 250 rpm

Photo, courtesy General Die and Stamping Co.





or linked to a pedal. Speed ranges of 3 to 1 or 4 to 1 are obtainable. Such motors are available in 1/6 to 3-hp sizes.

Successful application of this motor is usually limited to loads where the torque remains relatively constant throughout a given speed range.

IMPULSE MOTORS

Another small adjustable speed ac motor is the impulse motor, *Fig.* 78. Such motors are simple in design, low in cost, small in size, and light in weight. Speed is adjusted by a simple thumb-nut control. Such motors accelerate to rated speed almost instantly and stop quickly without overtravel.

The solid steel rotor is caused to turn by electromagnetic impulses. The electromagnet coil operates directly on ac power and the unit in *Fig.* 78 consumes only 9 watts of power. Motor is suitable for low horsepower applications where reciprocating and rotating elements require speed adjustment from time to time and fast starts and stops are involved.

SHADED-POLE MOTORS

Shaded-pole electric motors represent the smallest and simplest type of induction motor. They are low in cost and are inherently rugged. Fundamentally they are designed to operate at a constant speed. However, in applications for driving fans, blowers (*Fig.* 79), small pumps, etc., in which high starting torque is not necessary, motor speed can be controlled. In *Fig.* 80*a* is shown a basic pictorial representation of a subfractional horsepower shaded-pole motor. From this diagram it is apparent that speed can be adjusted by any method that adjusts main field current or shading coil current. A method of adjusting speed in one direction of a reversible shaded pole motor is shown in *Fig.* 80*b* and a shaded pole motor dynamic braking circuit is shown in *Fig.* 80*c*. At least four common methods can be employed to adjust shaded-pole motor speed by power input control:

1. Tapped or adjustable autotransformers
2. Tapped or adjustable resistors in series with motor
3. Tapped or adjustable inductors in series with motor
4. Tapped main field coils or a tapped shaded coil

While the tapped or adjustable autotransformer method, *Fig.* 81*a*, would be the most efficient method for speed control, this method is seldom used on shaded-pole motor speed control since transformer cost would approximate motor cost. In addition, the switching arrangement becomes complex, since the transformer must be disconnected from the line in the off position as shown in *Fig.* 81*a*.

The series resistance method, *Fig.* 81*b*, is the cheapest and simplest form of speed control. Tapped resistors or rheostats could be employed. The only drawback of this arrangement is power loss and heat developed in the resistor.

An inductive reactor arrangement, *Fig.* 81*c* and *d* has much lower power loss and heat development than the resistor control method. Commercial shaded-pole motors with two or three-speed controls, *Fig.* 82, commonly employ tapped series inductive reactors. This speed control method covers a wide power range—1/6 to 1/300-hp. An adjustable inductor is approximately double the size of the tapped inductive reactor. This point must be considered where space is an important factor.

Other speed control methods employ saturable reactors and buck-boost transformers.

The fourth method involves a special motor de-

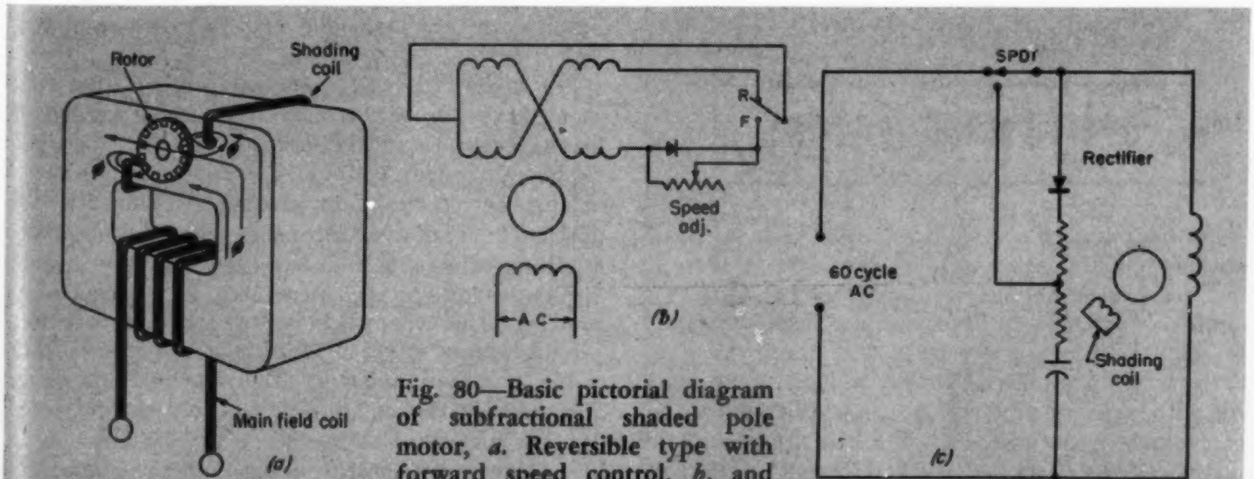
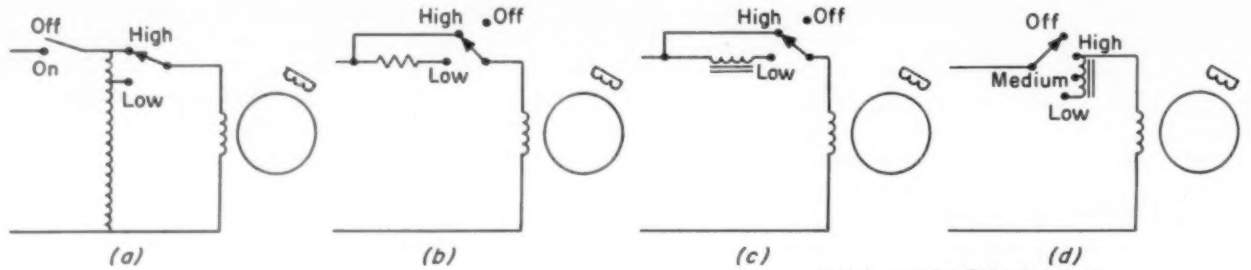


Fig. 80—Basic pictorial diagram of subfractional shaded pole motor, *a*. Reversible type with forward speed control, *b*, and dynamic braking circuit, *c*



Sketch, courtesy Ballastran Corp.

Fig. 81—Four types of circuits for input-power speed control of shaded-pole motors

Photo, courtesy Curtis Development and Mfg. Co.

Fig. 82 — Series-reactor type speed control for shaded-pole motors providing three forward speeds

sign. With tapped main field motor coils and shading coils, stepped speeds are provided with only a stepped switch. This method is most adaptable to larger diameter motors in the 1/6 to 1/30-hp range.

SPLIT-PHASE MOTORS

For starting, a split-phase induction motor has an auxiliary winding displaced electrically from the main winding but connected in parallel. The auxiliary winding is either opened after starting or connected-in permanently. The latter type is thus termed permanent split-phase induction motor. As with capacitor induction motors, speed can be controlled by adjustment of an autotransformer input voltage to either of these types. A method of obaining two speeds with a permanent split-phase induction motor is shown in *Fig.* 83. Here, different speeds are obtained by changing the winding connections to change number of poles. This system is usually employed for only two speeds, 2 to 1. Although other speed multiples are possible, additional main windings are required. Such motors are most commonly used to drive fans and blowers.

CAPACITOR MOTORS

A capacitor motor is a single-phase induction motor with a main winding arranged for direct connection to a source of ac power, and an auxiliary winding connected in series with a capacitor.

There are three basic types: (1) capacitor-start, (2) two-value capacitor, and (3) permanent-split. The first two types are not ordinarily adjusted in speed, either in steps or continuously. However, the permanent-split capacitor motor speed can be adjusted by reconnecting the split field windings as shown in *Fig.* 83.

To obtain ten speed steps, for example, with a permanent-split capacitor motor, it is convenient to use a tapped autotransformer for varying the voltages on the main and auxiliary windings, *Fig.* 83.

For highest speed—motor rated speed—the common connection of the main and auxiliary windings is connected to the transformer so as to provide them with equal voltage. For reduction in speed, voltage across the main winding is reduced by adjustment of the autotransformer. As the main-winding voltage is reduced, the auxiliary circuit-winding voltage is increased a corresponding amount. This change in voltage to the auxiliary circuit causes speed reduction of the motor to be a bit less than it would otherwise be. But it has the desired effect of improving starting and accelerating torques.

A new two-speed, double-winding, capacitor-start induction motor has recently been developed. In the application shown in *Fig.* 84, this new mo-

tor system not only can operate at two speeds but can be automatically reversed three times per minute. This motor design has high starting torque at either speed.

POLYPHASE SQUIRREL-CAGE MOTORS

Small amounts of speed reduction can be obtained by reducing input voltage to squirrel-cage motors. This can be done with adjustable rheostats or inductive reactors in series with input leads to the motor. These methods reduce pull-out torque, and regulation is poorer. Such methods may be applied to fan loads where torque varies with speed.

In applications where a few fixed speeds are adequate, speed of squirrel-cage motors can be adjusted by reconnection of windings. These motors are referred to as multispeed motors, *Fig.* 85.

In the case of two-speed motors, these are available in either single-winding type or two-winding type. In the case of the single-winding motors, such speeds as 1800/900, 3600/1800, 1200/600 and 900/450 rpm are obtained by bringing leads from the windings permitting reconnection of the motor from one speed to another by a method known as "consequent pole arrangement". Exact 2 to 1 ratios are the only speeds possible by a consequent pole connection.

Two-speed, two-winding motors permit the use of speeds other than of 2 to 1 ratio, such as 1800/1200, 1200/900, 900/600 rpm. In these cases one winding is utilized for each of the two speeds.

Four-speed motors are always of the two-winding type, with each winding reconnectable for con-

Photo, courtesy Emerson Electric Mfg. Co.

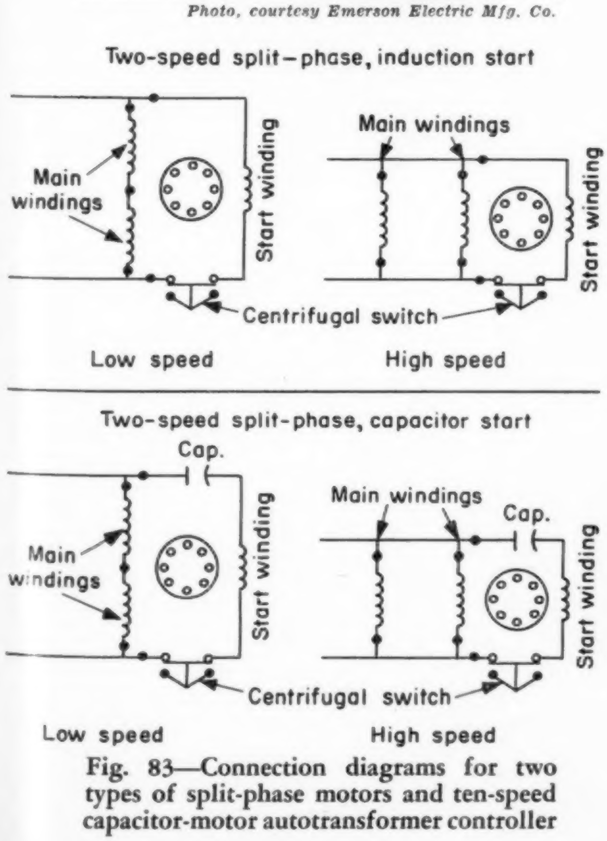
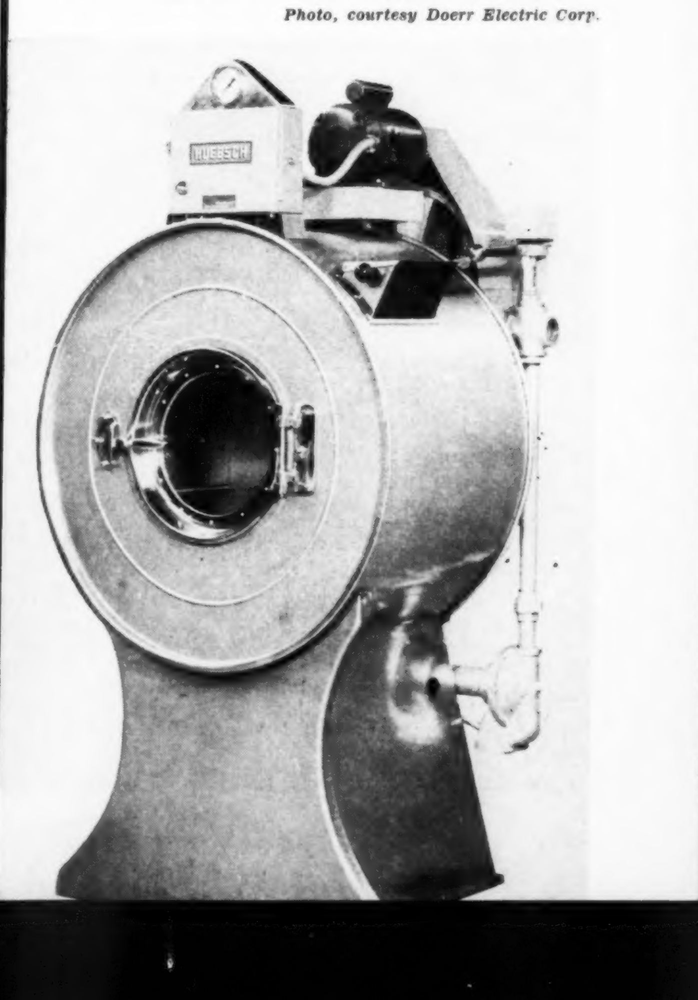


Fig. 83—Connection diagrams for two types of split-phase motors and ten-speed capacitor-motor autotransformer controller

Fig. 84 — Doerr Electric two-speed capacitor motor on Huebsch Mfg. Co. commercial clothes washer with Cutler-Hammer drum switch for dual speed control

Photo, courtesy Doerr Electric Corp.



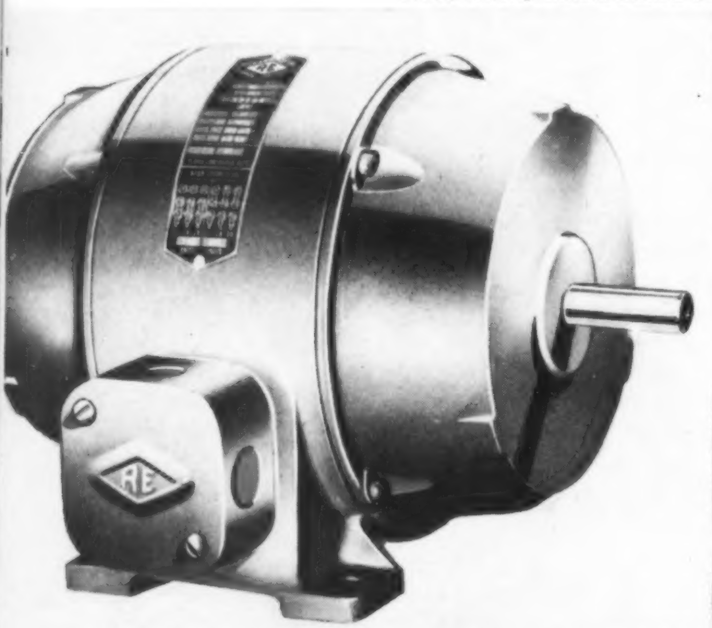
sequent pole arrangement, thus permitting four different output speeds. An application employing both a two-speed and a four-speed squirrel-cage motor is shown in *Fig.* 86.

Power versatility is provided for in multispeed motors since a single unit can be operated at different speeds to fit the needs of special jobs. These motors are available in either two, three or four-speed ratings and provide even further versatility in the following torque-horsepower-speed combinations:

CONSTANT TORQUE types of multispeed motors are used on equipment where the loads require a nearly constant torque regardless of the motor speed. With this type of motor the power output varies directly with speed. Typical applications include printing presses, conveyors, air compressors, etc.

Fig. 85—Multispeed polyphase squirrel-cage motor

Photo, courtesy Reuland Electric Co.



VARIABLE TORQUE types of multispeed motors are especially suited to powering loads that develop and maintain their momentum. With such loads, a reduction in operating speed is accompanied by a much greater reduction in required operating output power. For example, the power-to-speed reduction ratio of a variable-torque motor rated at 20 hp, 1800 rpm is 5 hp at 900 rpm. Typical applications include fans, blowers, centrifugal pumps, etc.

CONSTANT OUTPUT POWER types of multispeed motors are utilized on equipment where power output required is constant regardless of the operating speed. This feature is desired on jobs that require a constant amount of power such as encountered with a lathe where various speed and cutting characteristics are required for different diameters of work. Typical applications include drill presses, shapers, grinders, metal and woodworking lathes, boring machines, etc.

If wide continuous speed ranges are required with squirrel-cage motors, then adjustable-frequency systems must be used.

Changes in operating characteristics of a *Design* B squirrel-cage motor for small changes in frequency and voltage are listed in *Table* 16. A summary of speed adjustment characteristics is presented in *Table* 17.

Manual Controllers: Manually operated drum

Fig. 16—Effects of Voltage and Frequency Variations on Standard Squirrel-Cage Motors

Characteristic	Change in Rated Line Voltage (per cent) +10	−10	Change in Rated Line Frequency (per cent) +5	−5
Torque* Change (per cent)				
Locked-rotor and breakdown	+21	−19	−10	+11
Speed† Change (per cent)				
Synchronous	None	None	+5	−5
Full-load	+1	−1.5	+5	−5
Slip	−17	+23	Little change	Little change
Efficiency Change (per cent)				
Full-load	+0.5 to 1	−2	Slight increase	Slight decrease
¾-load	Little change	Little change	Slight increase	Slight decrease
½-load	−1 to 2	+1 to 2	Slight increase	Slight decrease
Power-Factor Change (per cent)				
Full-load	−3	+1	Slight increase	Slight decrease
¾-load	−4	+2 to 3	Slight increase	Slight decrease
½-load	−5 to 6	+4 to 5	Slight increase	Slight decrease
Current Change (per cent)				
Locked-rotor	+10 to 12	−10 to 12	−5 to 6	+5 to 6
Full-load	−7	+11	Slight decrease	Slight increase
Temperature Rise (C)	−3 to 4	+6 to 7	Slight decrease	Slight increase
Maximum Overload Capacity Change (per cent)	+21	−19	Slight decrease	Slight increase
Magnetic Noise	Slight increase	Slight decrease	Slight decrease	Slight increase

For typical general-purpose NEMA Design B squirrel-cage motors. Cited values vary somewhat for different ratings and designs. Data, courtesy Allis-Chalmers Mfg. Co.

*Locked-rotor and breakdown torque of ac induction motors vary as the square of voltage.

†Speed of ac induction motors varies directly with frequency.

controllers, *Fig.* 87, easily provide multispeed motor control up to 150 hp since the drums can easily be arranged with the necessary contacts for the sequence of operation. The ordinary drum switch does not provide low-voltage protection, overload protection, or reduced-voltage starting, but a standard motor starter is usually used ahead of the drum for needed protection. Since some drums are not designed for making or breaking the load current, additional contacts are used on the drum to close the starter when the drum is in a definite speed position and to open it before the drum contacts are opened. This prevents arcing or welding of the main current-carrying contacts of the drum.

Stators with more than one separate winding require at least one set of overload relays for each winding; with variable-torque motors this is considered sufficient. However, when a constant-horsepower motor or a constant-torque motor is used on a constant-horsepower load or a constant-torque load, one set of overload relays is required for each speed to protect the motor fully.

Magnetic Controllers: Used where the motor is remotely controlled or where an automatic pilot device, such as a pressure switch or a thermostat is needed, magnetic controllers, *Fig.* 87, are also used for frequent operation and severe service. They are

Photo, courtesy U. S. Electrical Motors Inc.

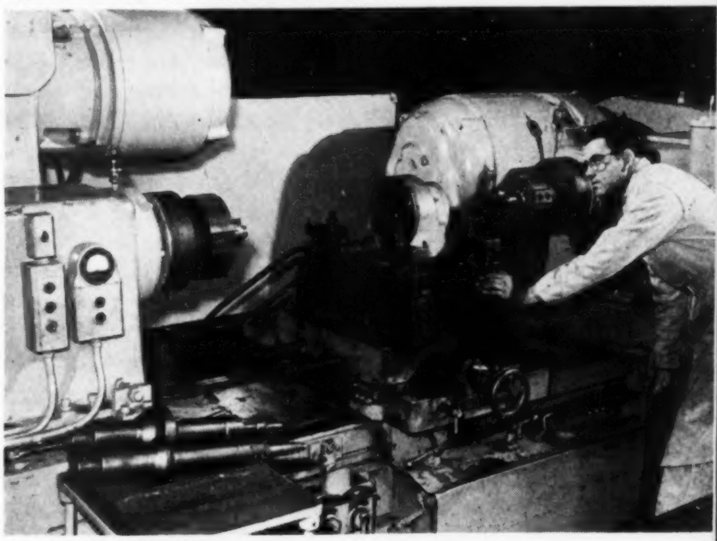


Fig. 86—Boring machine with multispeed squirrel-cage motors powering spindles. Two-speed motor drives mechanical adjustable-speed transmission on one spindle and four-speed motor powers other spindle

Table 17—Characteristics of Polyphase AC Motors

Type Motor	Starting Torque (per cent of full-load)	Breakdown Torque (per cent of full-load)	Stepless Speed Adjustment	Stepped Speed Adjustment	Output Power (hp)	Typical Applications
Squirrel Cage NEMA Design B*	100 to 250	200 to 300	Some with input impedance control; poor regulation	Multispeed types available with 2, 3 or 4 fixed speeds	½ to 200	Blowers, fans, centrifugal pumps, rotary compressors, machine tools, woodworking machines
NEMA Design C*	200 to 250	190 to 225	Some with input impedance control; poor regulation	Multispeed types available with 2, 3 or 4 fixed speeds	3 to 150	Agitators, conveyors, compressors, crushers, pumps, pulverizers
NEMA Design D*	Up to 275; depends on speed and rotor resistance	Usually stalls only at maximum torque which is at standstill	Some with input impedance control; poor regulation	Multispeed types available with 2, 3 or 4 fixed speeds	½ to 150	Bailers, bulldozers, cranes, die stamping machines, elevators, hoists, punch presses, shear machines
Wound Rotor	Up to 300; depends on external rotor resistance and distribution	200 with shorted slip rings	50 per cent speed reduction by rotor resistance control. Some with input impedance control; poor reduction by rotor resistance control		½ to several thousand	Ball mills, centrifugal and plunger pumps, compressors, conveyors, cranes, fans, hoists
Synchronous	40 to 160; depends on design	80 to 300; depends on design	None	Special motors designed for two fixed speeds	25 to several thousand	Constant-speed service

*NEMA Designs: B—Normal starting current, normal starting torque; C—High starting torque, normal starting current; D—High starting torque, high slip.

built for two, three and four-speed motors of either the separate winding or the reconnected type. They are usually the full-voltage type, but may be the reduced-voltage type, the same as the standard single-speed reduced voltage starters. There are three forms of multispeed magnetic starters: selective, compelling and progressive.

SELECTIVE CONTROL permits starting the motor on any desired speed winding. To change the speed of a running motor to a higher speed, the operator presses the desired speed button. However, to change to a lower speed the operator must press the stop button before selecting the lower speed. This allows time for the motor to decrease speed and thereby reduces shock on the driven machinery and surges on the power system. Occasionally on automatic controls, a time-delay relay is used to prevent the starter from changing from a high speed to a lower speed too quickly. This prevents sudden deceleration of the load.

COMPELLING CONTROL makes it necessary for the operator to increase speed from rest through each successive speed step in the proper sequence. To decrease speed, the operator must press the stop button and start at the lowest speed following the sequence to a new speed. This is required because of the conditions outlined in the foregoing paragraph.

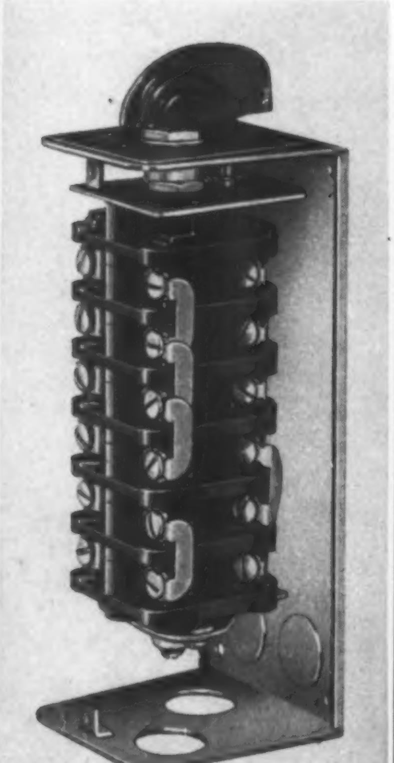
PROGRESSIVE CONTROL provides automatic, definite time-delay acceleration of the motor to the selected speed. To start the motor or raise the speed, the operator need only press the button for the desired speed. To change to a lower speed, the operator must press the stop button before selecting a new speed. With these starters, the motor cannot be started at a high speed and must progress automatically through the sequence of speeds.

POLYPHASE WOUND-ROTOR MOTORS

Speed of wound-rotor motors could be controlled by input voltage adjustment, as mentioned for squirrel-cage motors. However, a more economical and common method of speed adjustment is to insert resistance in the rotor circuit.

In construction, wound-rotor induction motors differ from the squirrel-cage type only in the rotor. Where the cage motor has short-circuited bars, the wound-rotor motor has definite windings (usually three-phase) in which leads are brought out to slip rings. External resistor connections for varying rotor resistance are made to brushes riding on these slip rings. In a wound-rotor motor, the stator is commonly called the primary and the rotor the secondary, because, under locked-rotor conditions, the motor is a transformer with a given ratio. This ratio depends on motor design and is not standardized.

An induction motor develops maximum torque when the motor resistance is equal to the slip multiplied by the motor reactance. In a squirrel-cage induction motor, the starting torque is considerably lower than the maximum or breakdown torque since the rotor resistance is relatively low and constant in comparison to reactance at standstill.



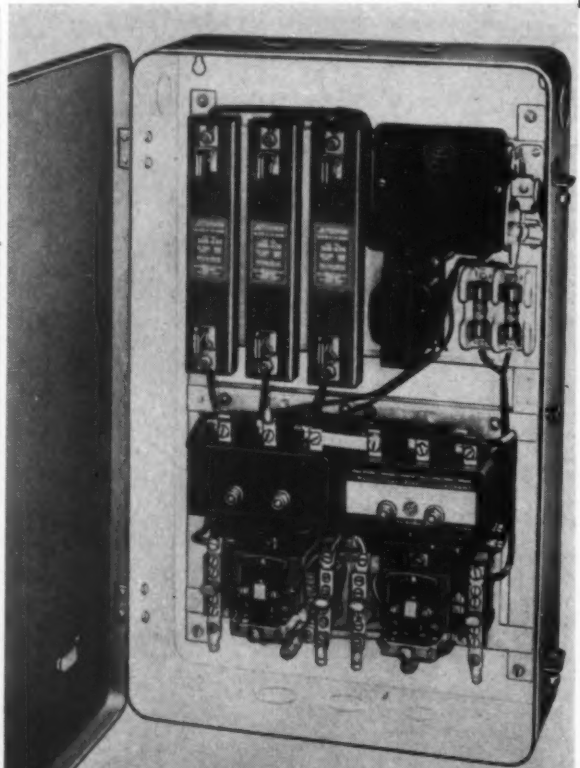


Fig. 87—Drum switch for manually starting, speed changing, and reversing polyphase multispeed motors, left, and magnetic multispeed motor starter, right

Photo, courtesy Allen-Bradley Co.

ADJUSTABLE-SPEED ELECTRIC-MOTOR DRIVES

The starting current drawn from the line with a wound-rotor motor is less than that required by a squirrel-cage motor for the same starting torque.

A given value of torque requires a definite value of stator flux and rotor current. Any increase in rotor resistance tends to reduce rotor current and motor torque. To obtain a definite value of torque, the motor will slow down to increase the induced rotor voltage in order to maintain the rotor current, the stator flux being practically constant. Thus, changing the rotor resistance is a means of controlling motor speed.

Wound-rotor motors are particularly adaptable to applications requiring high starting torque or speed control where speed ranges of 2 or 3 to 1 are acceptable. Typical applications include cranes, hoists, elevators, pumps, crushers, rolling mills, wood pulp grinders, etc. Sizes available run into the thousands of horsepower.

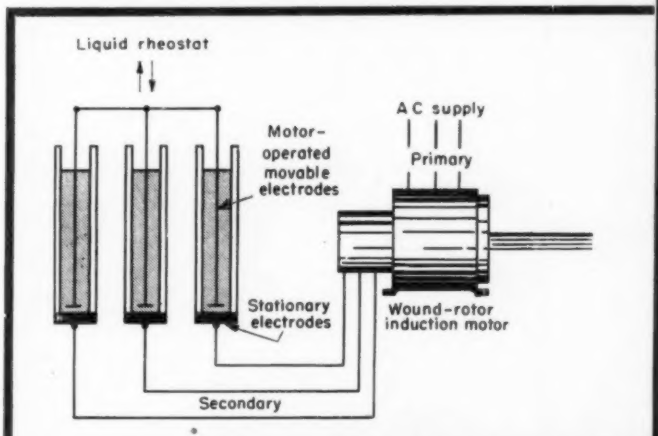
The control equipment for a wound-rotor motor includes a primary starter to connect the motor to the supply line, and a device for commutating the rotor to secondary resistance.

Primary Control: Since the primary is the same as that of a cage motor, the primary control requires a standard cage motor starter of the full-voltage type. This starter is required to provide the necessary overload protection as well as undervoltage protection or release. The starter may be manual or magnetic, high or low-voltage and may incorporate short-circuit protection. Reversing of the motor may be accomplished with a reversing primary starter in the same manner as for a squirrel cage motor.

The primary control is electrically interlocked with the secondary controller in such a manner that the motor cannot be connected to the line unless all of the secondary resistance is inserted in the secondary circuit by the secondary controller. If a circuit breaker is used in the primary, it must have a magnetic lock attachment, interlocked with the secondary controller, so that it cannot be closed to connect the motor to the line unless the secondary controller is set for maximum resistance.

Secondary Control: For varying the resistance in a rotor circuit to provide secondary control of wound-rotor motors one of the following five controls may be used:

1. Manual nonreversing starting drum controller
2. Manual nonreversing speed-regulating drum controller



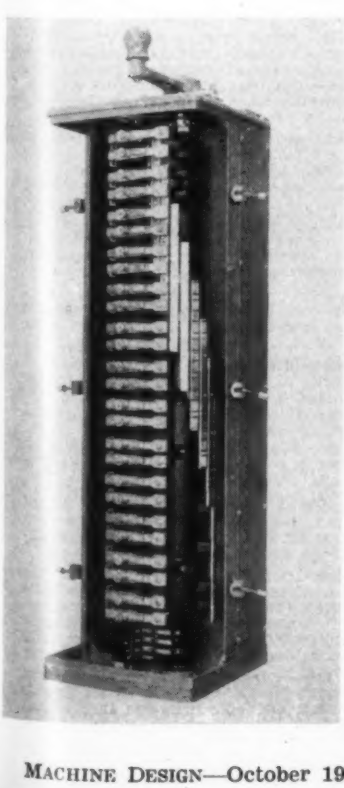


Fig. 88—Left—Drum speed controller for rotor-resistance control of wound-rotor motors

Photo, courtesy Cutler-Hammer Inc.

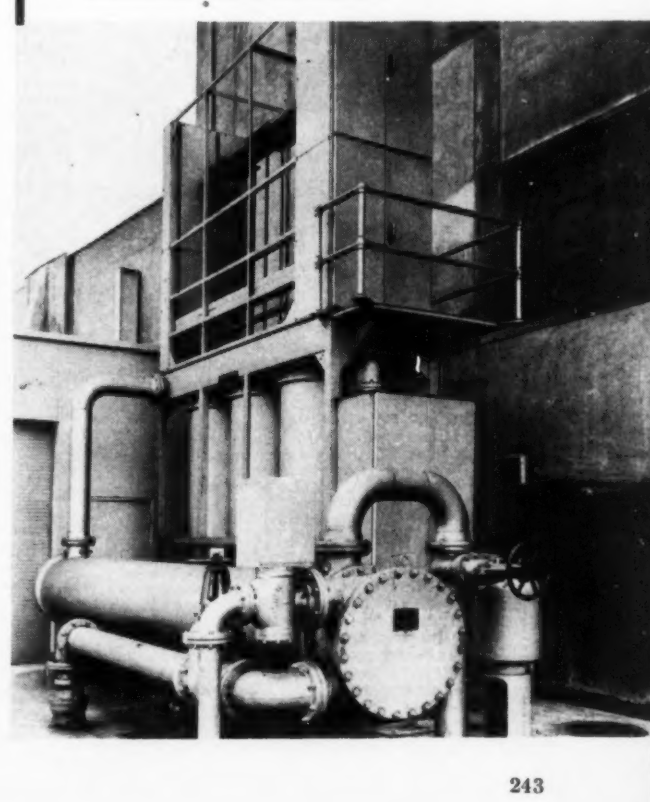


Fig. 89 — Right — Liquid rheostat control of wound-rotor motor

Photo, courtesy Westinghouse Electric Corp.

3. Manual reversing drum controller
4. Liquid rheostat
5. Magnetic contactor type secondary control

The most common type secondary controller is the cylindrical drum with contact segments which touch sliding finger contacts, *Fig.* 88. The main portion of the drum is a cast cylinder with the shorting segments mounted directly on it. The cam type controller switch is sometimes used for secondary control and, with this method, rotating cams close contact fingers at different points as the cam shaft is rotated.

Liquid Rheostat Control: The liquid rheostat is used for wide-range, smooth speed regulation of wound-rotor induction motors driving loads with definite speed versus load characteristics, such as fans, blowers and pumps. They are also used for current control or for starting control of heavy constant-torque loads.

In general, liquid rheostats, which use water for

COMMON ELECTRIC ADJUSTABLE SP

Armature reaction—Effect resulting from the electro-magnetic action set up by the rotating armature.

Autotransformer—Transformer in which a part of the winding is common to both primary and secondary circuits.

Braking, dynamic—System of braking in which the motor is used as a generator, and the kinetic energy of the motor and driven machinery is employed as the actuating means for exerting a retarding force. Energy produced may be absorbed, for instance, by suitable resistors.

Braking, regenerative—Form of dynamic braking in which the kinetic energy of the motor and driven machinery is returned to the power-supply system.

Circuit breaker—Device designed to open an electric circuit by the operation of an electromagnetic or thermal device for the purpose of protecting a circuit and connected electrical equipment against abnormal conditions, such as short circuits or overloads, which might cause damage.

Command—Input signal to a regulator which is established or varied by some means external to, and independent of, the feedback control system under consideration.

Compounding—Field winding design of a compound generator that provides the same voltage output at no load as at full load when operating at rated speed, voltage, and temperature.

Contact drop—Drop in voltage due to resistance between face of the brush and surface of the commutator.

Contactor, clapper — Magnetic contactor hinged at one end for opening or closing an electric circuit.

Contactor, magnetic—Device for repeatedly establishing and interrupting an electric power circuit by electro-magnetic means.

Contactor, solenoid—Magnetic contactor which functions by the action of a solenoid coil on a movable plunger for the repeated opening or closing of an electric circuit.

Contacts, auxiliary—Small contacts which open and close the control circuit.

Control accuracy—Degree of correspondence between an ultimately controlled variable and the ideal value. The term *accuracy* has also come to mean the amount speed will deviate from a preset value.
Also see *Deviation, system*.

Control, armature—Speed controlled by adjustment of the voltage applied to the armature terminals of the motor.

Control, closed-cycle — Control system which is self-regulatory.

Control, field—Speed controlled by adjustment of the voltage applied to the field of a d-c machine.

Control system, automatic—Any operable arrangement of one or more automatic controllers connected in closed loops with one or more processes.

Control, Ward Leonard—System of speed control in which the drive motor is powered by a generator with an adjustable-voltage output.

Controller—Device or group of devices which governs in a predetermined manner the electric power delivered to apparatus to which it is connected.

Controller, automatic — Device which measures the value of a variable quantity or condition and operates to correct or limit deviation of this measured value from a selected reference. An automatic controller includes both the measuring means and the controlling means. True automatic control systems always contain one or more feedback loops at least one of which includes both the automatic controller and the process.

Controller, cam—Form of drum controller in which the contact fingers are actuated by cams mounted on a rotating shaft.

Controller, drum — Manual controller in which electric contacts are made between stationary fingers and segments on a rotating cylinder.

Controller, electric—Electric control equipment which varies, changes or modulates in a predetermined manner electric power delivered to apparatus, such as a motor, to which it is connected.

Controller, magnetic—Electric controller in which part or all of its basic operations are performed by electromagnets.

Controller, manual — Electric controller having all its basic functions performed by hand.

Controller, multiple-switch — Mechanism consisting of a series of toggle-operated switches each of which removes a step of resistance when closed for the purpose of reduced-voltage starting.

Controller, relay-operated — Controller in which the energy transmitted through the primary element is either supplemented or amplified for operating the final control element by employing energy from another source. This type of automatic controller may have either a self-operated measuring means and a relay-operated controlling means, or a relay-operated measuring means and a relay-operated controlling means.

Controller, self-operated — Controller in which all the energy to operate the final control element is derived from the controlled medium through the primary element. This type of controller must have both self-operated measuring means and self-operated controlling means.

Current limit acceleration—System of control in which acceleration is so governed that the motor armature current does not exceed an adjustable maximum value.

Deviation, command transient speed—Deviation caused by a change in speed setting. This creates temporarily an error voltage which the regulator tries to eliminate by bringing motor to new desired speed value. There are transients caused by this motor speed change and overshoot of the preset value before the system settles to steady-state values.

Deviation, load transient speed—Deviation from desired speed due to load disturbances. Normally greater than steady-state deviation. Maximum value depends largely on motor and load inertias, inherent regulation of drive system, and speed of response of the regulating system. High inertias reduce maximum deviation but increase recovery time unless regulator gain is considerably increased.

Deviation, peak command transient — Peak value of the ultimately controlled variable minus the ideal value when a specified load change is applied.

Deviation, peak load transient — Peak value of the ultimately controlled variable minus the ideal value when the command is constant.

Deviation, steady state—Steady state value of the ultimately controlled variable minus the ideal value when the command is constant.

Deviation, steady-state speed—Closely approximates the total no-load to full-load regulation of the combined machines in a drive system divided by the system gain or amplification.

Deviation, system—Value of the ultimately controlled variable minus the ideal value. This deviation is usually expressed as a plus or minus percentage of the desired speed. Reasons for deviation include (1) electrical component changes, (2) power-supply changes, (3) load changes, and (4) command changes (change of speed setting).

Drop-out—Opening of a magnetic contactor, or reduced voltage at which it opens.

Duty, continuous—Service requirement demanding operation at a substantially constant load for an indefinitely long time.

Duty, intermittent — Service requirement demanding operation for alternate intervals of (1) load and no-load, (2) load and rest, or (3) load, no-load and rest. Examples: freight and passenger elevators, tool head, pumps, drawbridges, turntables.

Duty, periodic — Intermittent duty in which the load conditions are regularly recurrent. Examples: rolls, ore and coal-handling machines.

Duty, short-time—Service requirement demanding operation at a substantially constant load for a short and definitely specified time. Examples: operating valves, raising or lowering rolls.

Duty, varying—Service requirement demanding operation at loads and for time intervals which may both be subject to wide variation.

Efficiency, overall drive—Per cent mechanical power output to electrical power input including control equipment power and conversion equipment losses.

Exciter—Auxiliary dc generator or rectifier which supplies energy for the field excitation of a motor or generator.

Excitron—Electronic tube with a pool of mercury for the cathode and an exciter electrode employed to establish the electron flow in addition to the usual anode.

Generator, tachometer—A small ac or dc generator employed for accurate speed indications and other control functions. Also referred to as pilot generator.

Hunt—To swing back and forth, alternately overshooting and undershooting a desired fixed point, in effort to seek equilibrium.

Ignitron—Electronic tube with a pool of mercury for the cathode and an ignitor electrode to continually re-establish the electron flow in addition to the usual anode.

Inrush current—Maximum value of current at the instant a motor at rest is connected to the supply line.

Interpole—Auxiliary magnetic pole placed between the main field poles of an electric machine to permit proper commutation.

IR drop compensation—Provision in the system of the control by which the voltage drop (and corresponding speed drop) due to armature current and armature circuit resistance is partially or completely neutralized.

Iron loss—Popularly applied to the loss of energy in an electric machine due to hysteresis and eddy currents in the iron mass.

the resisting medium, are safe, inexpensive, compact, simple with a minimum of parts, and have no metallic contacts to be destroyed by arcs.

In the modern three-phase liquid rheostat, three insulated cells or containers are mounted side by side, one for each phase of the wound-rotor secondary, *Fig.* 89. These cells contain the electrolyte (water) which functions as the resistance. Within each cell is a stationary electrode and a movable electrode. Motor speed is adjusted by raising or lowering the movable electrode and electrolyte level within the cells. This changes the resistance by varying both the distance between the electrodes and the current carrying area of the electrolyte. Since the electrolyte is a function of the resistance, its level must be controlled. Liq-

SPEED DRIVE TERMS

Limit circuits—Circuits for limiting current, voltage or both in drive systems caused by transient load, speed, and power supply changes. Response characteristics are impaired with such circuits and must be considered in original system design.

Magnetic amplifier — Saturable reactor used either alone or with other components to obtain amplification and control of ac or dc power.

Motor, adjustable-speed — Motor whose speed can be varied gradually over a considerable range, but whose speed when once adjusted remains practically unaffected by the load. For example a direct-current shunt-wound motor with field-resistance control designed for a considerable range of speed adjustment.

Motor, adjustable varying-speed — Motor whose speed can be adjusted gradually, but whose speed, when once adjusted for a given load varies in considerable degree with change in load. For example, a direct-current compound-wound motor adjusted by field control or a wound-rotor induction motor with rheostatic speed control.

Motor, constant-speed — Motor whose speed of normal operation is constant or practically constant. For example, a synchronous motor, an induction motor with small slip or a direct-current shunt-wound motor.

Motor, multispeed—Motor which can be operated at any one of two or more definite speeds, each being practically independent of the load. For example, a direct-current motor with two armature windings or an induction motor with windings capable of various pole groupings.

Motor, stabilized shunt—Shunt-wound motor having a light series winding added to prevent a rise in speed or to obtain a slight reduction in speed with increase of load.

Motor, variable-speed—See ***Motor, adjustable-speed.***

Motor, varying-speed—Motor whose speed varies with the load, ordinarily decreasing when the load increases. For example, a series-wound or repulsion motor.

Phase shift—Phase angle between plate voltage and grid voltage as applied to grid-controlled electronic rectifiers.

Pickup—Popularly applied to the closing of a magnetic contactor or to the increase in voltage which causes it to close.

Pilot device—Sensing element which initiates a signal that introduces signal changes into a controller. This may be a manually operated device such as a simple off-on switch or drum controller, or it may be a transducer such as electric tachometer generator, thermocouple, etc.

Pilot generator—See ***Generator, tachometer.***

Plugging—Throwing a motor from full speed in one direction to full speed in the opposite direction.

Rectifier, controlled electronic—Rectifying device in which conduction can be initiated at any instant in the positive part of the cycle. By varying the ignition point, average value of current flowing through the tube or tubes to the connected load can be adjusted over a relatively wide range.

Relay—Device by means of which contacts in one circuit are operated by a change in conditions in the same circuit or in associated circuits.

Residual magnetism—Magnetism permanently retained in a piece of iron after the magnetizing agent has been removed.

Residual voltage—Voltage developed by a generator from the residual magnetic flux in the field poles.

Response time—Period of time occurring between application of a specified disturbance or command to the time the ultimately controlled variable is permanently within the limits of steady-state deviation.

Rheostat — Adjustable resistor so constructed that its resistance can be changed without opening the circuit to which it is connected.

Rheostat, face-plate—Adjustable resistor for heavy-current applications. Rheostat consists of a series of contact segments or buttons mounted on an insulated face plate. Contact buttons are wired to a series of resistor elements of proper capacity.

Rheostat, plaque type—Adjustable resistor consisting of an asbestos insulating board or ceramic form on which resistance wire or ribbon is wound. Contact buttons, arranged in a small arc, are connected to several points along the resistance wire.

Rheostat, plate—Adjustable resistor consisting of a series of contact buttons arranged in a circle and connected at many points to an embedded resistive element.

Rheostat, ring type—Adjustable resistor consisting of a resistive element of either wire or ribbon toroidally wound on a ring of ceramic insulating pottery or insulated metal.

Rheostat, slide-wire—Same as *Rheostat, sliding contact.*

Rheostat, sliding-contact—Adjustable resistor of heavily oxidized wire or ribbon wound on a tube of heat-resistant insulating material. A sliding contact on a guide rail provides power adjustment.

Saturable reactor—Reactive iron-cored inductance element used to control alternating-current power.

Service factor—Ratio of continuous overload which may be safely applied to a general-purpose motor at rated voltage and frequency without overheating to normal load. For fractional-horsepower motors this factor may range from 1.25 to 1.4, with higher values applying to smaller horsepower ratings. For integral-horsepower motors, service factor may range from 1.15 to 1.25. Above 3 horsepower, standard service factor is 1.15.

Shorted out—Means of removing a device from an electric circuit by short circuiting its terminals.

Shunt — Branch conductor connected in parallel with the main conductor, or a device arranged to permit only a small portion of the current of a circuit to energize a sensitive instrument.

Solenoid — Hollow cylindrical winding which acquires the properties of a magnet when a current flows through it.

Speed adjustment—See ***Speed control***

Speed, base (adjustable-speed motors)—Lowest rated speed obtained at rated load and rated voltage at the temperature rise specified in the rating.

Speed change—Speed variation due to load or adjustment.

Speed control—Manipulation or control of the speed of a motor by manual operation or by an automatic device. Speed changes produced in this way are independent of the inherent changes in speed due to load upon the machine.

Speed deviation—See ***Deviation, steady-state speed, load transient speed,*** and ***command transient speed.***

Speed range—All speeds which can be obtained in a stable manner by action of part (or parts) of the control equipment governing the performance of the motor. Speed range is generally expressed as the ratio of maximum to minimum operating speeds.

Speed, rated—Speed of an electric motor when rated voltage is applied to the motor terminals and the motor is driving a rated motor-nameplate horsepower load.

Speed-regulating system — Speed-control system in which some form of feedback is introduced for the purpose of reducing inherent variations in speed which would otherwise occur with changes in load, motor input voltages, etc.

Speed regulation—Change in speed of an electric motor as load is placed upon it when operating at constant terminal voltage. Defined as the ratio of the difference between no-load and full-load speed to the speed at full load expressed in per cent.

Speed setting—Selection of an operating point at a given condition of load by movement of the adjusting device.

Speed step—A definite change in speed due to adjustment. Term is usually not applied to continuously adjustable drives since the speed steps would be essentially infinite in number.

Speed variation—Change in motor speed above or below, or both, from a desired speed value due to changes in load or input power.

Speed variation, inherent — Changes in speed which occur with changes in load, motor temperature, etc.

Starter—Electric controller for accelerating a motor from rest to normal speed.

Starter, across-the-line—Starter arranged to place full line voltage on the machine without intermediate resistor steps.

Starter, face-plate—Manual starter with a movable arm which sweeps over a row of stationary contacts mounted on a flat surface for the purpose of removing steps of resistance from the circuit.

Surge—Sudden rush of electric current in a circuit at the instant the circuit is closed, or a sudden load thrown on it.

Switch, master—Switch which dominates the operation of contactors, relays or other magnetically operated devices.

Tachometer—A device for measuring rotational speed in revolutions per unit of time. May use frequency, ac or dc voltage, or ac or dc current as a sensing signal.

Thyratron—An electronic tube containing inert gas or mercury vapor under low pressure and three electrode elements.

Torque, breakaway—Total torque developed in a motor armature to start rotation.

Winding, compensating—Winding designed to neutralize the armature cross field, wound in series with the armature through slots across the face of the pole pieces.

uid level is maintained just above the movable electrode by a weir or gate which moves up and down with the movable electrode.

The electrolyte is in constant circulation, passing through a heat exchanger where the heat caused by the current passing through the electrolyte is dissipated. By proper design, almost any type of resistance versus position curve can be obtained, giving equal speed changes per unit of rheostat travel.

Many other methods of speed control of wound-rotor motors have been developed. These systems, some of them quite complicated, do not find wide application.

Photo, courtesy McCleery Engineering and Mfg. Co.

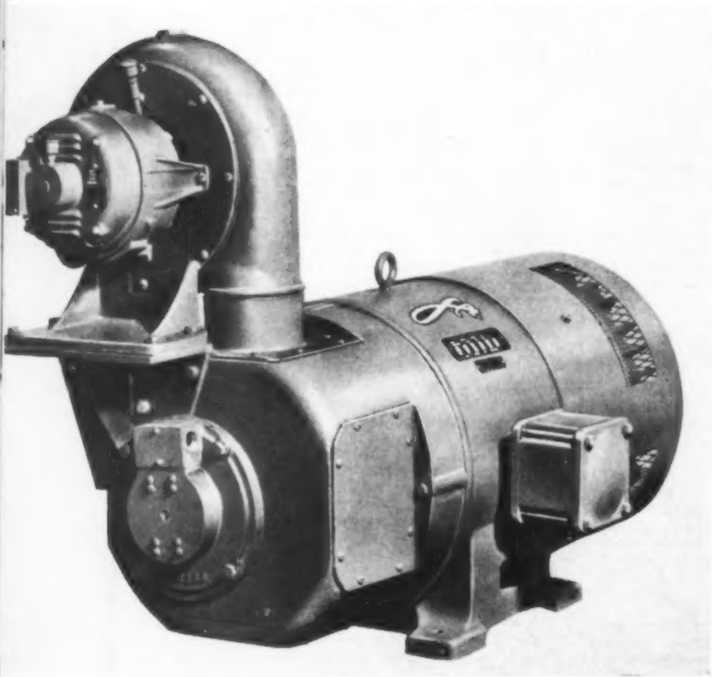


Fig. 90—Above—Louis Allis Co. 50-kw adjustable-frequency converter for powering several ac motors. Frequency output is adjustable through a 15 to 50-cycle range

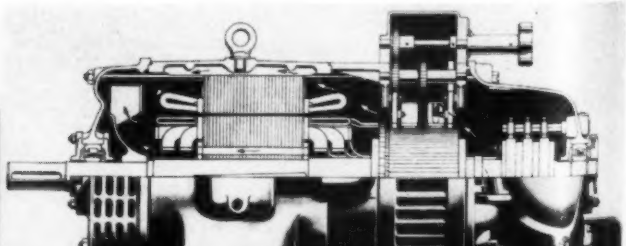
SYNCHRONOUS MOTORS

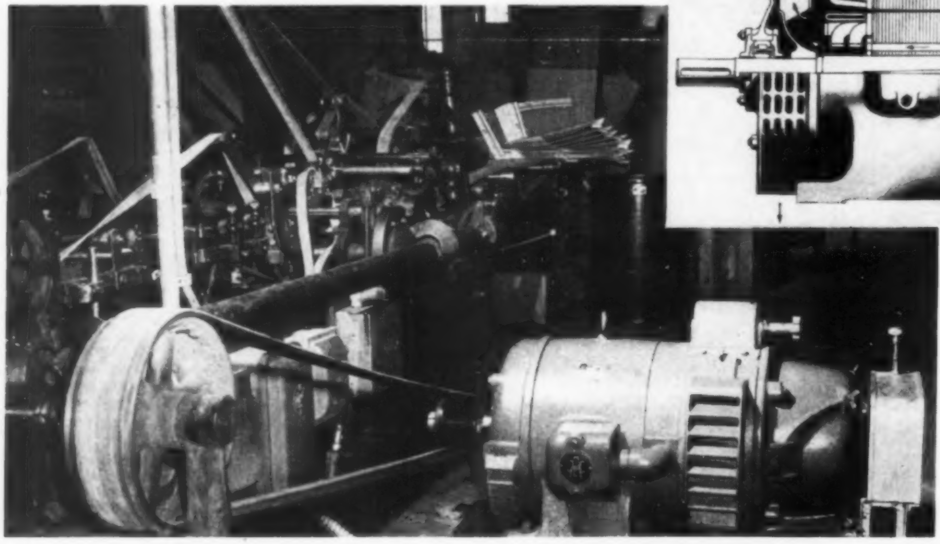
Since the synchronous motor operates at exactly synchronous speed, speed adjustment methods are usually complex and expensive. Adjustable-frequency systems are employed where speed regulation must be zero or in multiple-motor drive systems where exact synchronization between motors is required. Some type of frequency converter must be provided, *Fig.* 90. Synchronous motors can be designed to permit reconnection of windings to obtain different speeds.

SCHRAGE MOTORS

Another ac motor that has relatively wide speed range is the three-phase brush-shifting polyphase shunt motor, *Fig.* 91. This motor was originally known as the Schrage Motor and has an adjustable constant-speed characteristic with good torque and efficiency. The motor is basically a polyphase induction motor with a primary winding on the rotor and an insulated secondary winding on the stator. The stator winding is connected to movable brushes. When these brushes are shifted apart, a slip-frequency voltage is applied to the stator winding, thereby causing speed changes.

Such motors have regulation of 10 per cent or better at top speed and about 20 per cent at low speed, and the operating range may be as high as





Photo, courtesy Belgian Electric Sales Corp.

Fig. 91 — Machine built by International Paper Gluing Machine Co. with 10-hp brush-shifting polyphase motor. Application calls for speeds between 300 and 1500 rpm

20 to 1, although not continuously. It has good efficiency at low speed and is suitable for continuous operation at approximately 4 or 5 to 1. Control is by a standard reversing or nonreversing starter with automatic or remote speed selection, if desired. Horsepower ranges of 3 to 60 are common although sizes to several hundred horsepower have been built.

They find application in textile machines, fans, pumps, conveyors, packaging machinery, paper mills, etc.

LOAD POWER DETERMINATION

It may be somewhat difficult and tedious to calculate power required by a load throughout a given speed range. If the machine, or a prototype, is available load power can easily be determined by experimentally driving the load with a dc motor. A direct-current ammeter of suitable capacity can be placed in series with the dc motor armature and a dc voltmeter across the armature. With no load connected to the motor, readings can be made of no-load armature current (sometimes called idle current) and applied no-load voltage with the armature rotating at a number of speeds which are of interest throughout the speed range.

Then, load can be applied to the motor and measurements made of armature current and voltage under load conditions at the same speed points picked for the no-load conditions.

With power to the motor off, armature resistance should next be measured—while the armature is still hot.

Power required to drive the load in horsepower for each speed point is given by (See *Nomenclature*, Page 191)

$$P = \frac{E_{tL}\, I_{aL} - E_{tNL}\, I_{aNL} - R_a\, (I_{aL} - I_{aNL})^2}{746}$$

Where the load on a machine varies with time and/or speed varies with time, but either or both change value at regular intervals, the motor size required can be calculated by the root-mean-square method. In this method the power in horsepower for each load condition and speed condition is determined either by measurement, as outlined, or by other mathematical approaches. These horsepower values are then squared and multiplied by the time duration for a given torque and speed condition. These values are then used in

$$P = \sqrt{\frac{P_1^2\, t_1 + P_2^2\, t_2 + P_3^2\, t_3 + \ . \ . \ . \ + P_n^2\, t_n}{t_1 + t_2 + t_3 + \ . \ . \ . \ + t_n}}$$

to determine the root-mean-square output power requirement of the motor. Thus, motor size sufficient to operate a load on a given duty cycle may be smaller than required to operate continuously at a given load and speed.

Of course, at low speeds motor heating becomes a problem and the use of the root-mean-square formula would have to presume sufficient motor cooling. Otherwise, the motor would have to be derated accordingly.

Acceleration Factors: Motor starting torque may range from 10 per cent to as high as 350 per cent of full load torque, depending on starting requirements of the load and starting limitations of a particular motor or a complete drive. Starting torque limitations depend on a number of factors, such as motor type, frequency of starting, ambient and motor temperature, lubrication, characteristics of the power input, etc.

Frequency of starting appreciably affects motor size, particularly if a machine has a high moment of inertia (Wr_g^2). The large inrush of current at start, coupled with frequent starting, tends to cause a motor to overheat unless the motor is of sufficient size to dissipate the added heat created by such service.

Naturally, starting torque supplied to a machine is usually higher than at points between starting and any desired speed. Of course, the higher the starting torque, the more rapid the acceleration. An approximation of torque that is required to accelerate a rotating mass from rest to any particular speed is given by

$$T = \frac{(\Delta S)\, Wr_g^2}{308\, t}$$

Usually, if the acceleration time is greater than

20 seconds, special starters, speed controls, and motors are required to prevent overheating.

The flywheel effect or inertia of rotating elements of motor and its driven machine will appreciably affect acceleration time. This, in turn, will affect motor heating.

A formula for determining available horsepower required to accelerate a given motor and its driven load from rest to a particular speed in a given length of time is given in.

$$P = \frac{(\Delta S)^2 \, W r_g^2}{1.617(10)^6 \, t}$$

Where motors are applied in a rather regular duty cycle and acceleration power is a significant factor, the above acceleration power formula may be incorporated in the root-mean-square power formula on the preceding page. This acceleration power becomes more and more important as motor and load moments of inertia increase.

FUTURE DESIGN MANUALS

This article has dealt in some detail with only one general means of obtaining adjustable speed in design. Concerned exclusively with speed control of electric motors, it has not covered a number of methods that might be considered electric adjustable speed drives in the broad sense.

For example, electric slip couplings—eddy-current, magnetic-particle, and hysteresis devices—are well established and growing in their proved application to adjustable-speed service.

Moreover, equalling the great array of electric drives discussed in this article are adjustable-speed drive methods in mechanical and fluid-power forms with their host of control techniques.

Selecting or designing the best drive for adjustable-speed service may often be an easy matter—matching obvious requirements with the self-evident or readily recognized solution. However, in new design situations and in the constant upgrading of machine performance, knowledge of all basic methods and their control possibilities is a potent aid.

MACHINE DESIGN, through a series of equally comprehensive articles on all other means of speed adjustment, will continue in future months to publish basic guides in this design area. In composite form, they will be a manual on adjustable-speed drives in design.

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Clearance Design in Hydraulic Pumps and Motors

How to find the optimum clearance by taking into account the variation in viscosity that occurs with heat generation in the slip passages of positive-displacement units

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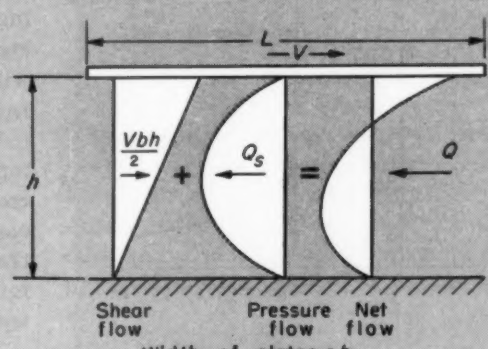


Fig. 1—Idealized slip passage showing flow components

DESIGN of clearances in positive-displacement pumps and motors has been discussed in earlier publications.[1] Elementary theory used in the design procedure was based upon the assumption that viscosity of the liquid is a constant. This led to the prediction of an optimum clearance for a given set of operating conditions and was also the basis for the suggestion that pumping of extremely viscous liquids[2] could be accomplished with pumps having very large clearances and developing high efficiencies.

It was shown that the efficiency of a pump or motor was controlled almost exclusively by the clearances. This was a point of considerable significance that led to the development of a completely new concept of performance analysis and interpretation. However, these developments have not received wide acceptance and this may be traced, at least in part, to the fact that the elementary theory was based on an assumption that could not be true in practice. It is clearly recognized that there is heating of the liquid in the clearance passages, and a consequent decrease in the viscosity which must necessarily affect performance. A qualitative evaluation of this effect was made in a previous publication of the author.[3] However, no quantitative analysis of the effect of the internal heating has been set forth.

There have been obtained various experimental results that could not be explained by the elementary theory, particularly some that showed a periodicity in the relationship between the slip flow and the pressure or the speed of rotation of the pump. In addition, slip flow always exceeded that predicted by the theory, thus resulting in a lack of confidence in the theory on the part of designers.

In a theoretical analysis[4] the author included the effect of temperature rise and consequent variation in viscosity and predicted the nature of the flow in a slip passage through the walls of which no heat flowed. The present exposition is concerned with the application of this theory to the design of clearances.

[1]References are tabulated at end of article.

Constant Viscosity Theory: For ready reference the equations for the constant viscosity theory are reviewed and presented here.

In *Fig.* 1 is shown an idealized slip passage which has width b, length L, and depth h. Viscosity of the liquid is μ, velocity of the moving boundary is V, and difference in pressure between the ends in the length direction is Δp.

The flow shown in the diagram, as the sum of the shear flow to the right and the pressure flow to the left giving a net flow to the left, corresponds to one of three possible cases. The second one would be with the shear flow and the pressure flow as indicated in *Fig.* 1 and the net flow to the right, and the third case would be with the shear flow and the pressure flow both to the right resulting in a net flow to the right.

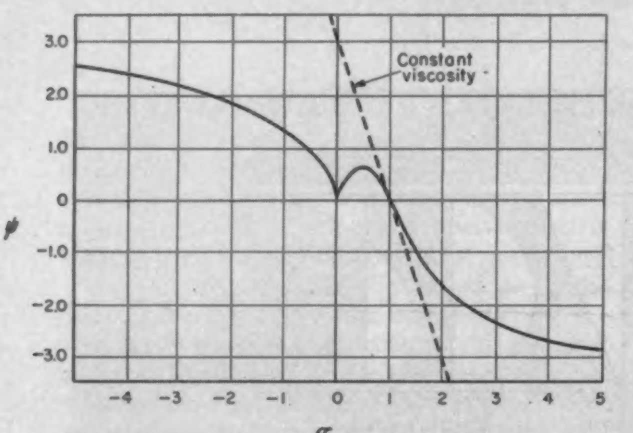


Fig. 2—Plot of Equation 5, where ψ is a function of the pressure difference and the characteristics of the liquid and α is a function of the slip passage and the flow

The slip Q_{sc} in the case of constant viscosity is

$$Q_{sc} = \frac{(\Delta p)\, bh^3}{12\,\mu\, L} \qquad (1)$$

The power loss P_L due to the slip flow and the viscous drag on the plate is

$$P_L = \frac{(\Delta p)^2\, bh^3}{12\,\mu\, L} + \frac{\mu\, V^2}{h}\, bL \qquad (2)$$

The optimum clearance h_{oc} corresponding to the minimum power loss is

$$h_{oc} = \sqrt{\frac{2\,\mu\, VL}{(\Delta p)}} \qquad (3)$$

In distinguishing the flow with constant viscosity from that with variable viscosity, the subscripts c and v, respectively, will be used. Accordingly, the subscript oc means optimum with constant viscosity; the subscript ov means optimum with variable viscosity.

Variable Viscosity Theory: The theory including consideration of the generation of heat by viscous action and consequent decrease in the viscosity is based upon the assumption that all of the energy expended in viscous action is converted into heat and retained in the liquid. This viscosity is assumed to vary in accordance with

$$\mu = \mu_0\, e^{-\beta T} \qquad (4)$$

where μ is the viscosity at the temperature T and β is a coefficient depending upon the physical char-

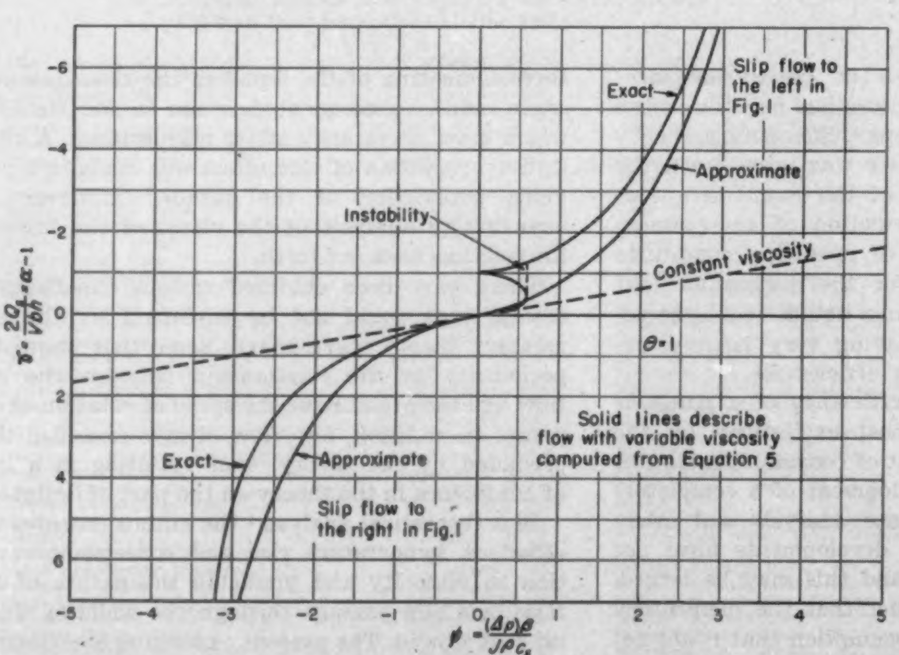


Fig. 3 — Plots, analagous to *Fig.* 2, showing comparison of results obtained with different approximate equations

acteristics of the liquid. The coefficient has the dimensions $1/T$. The quantity μ_0 is the viscosity at the temperature zero.

The result of this theoretical development is

$$\psi = \mp \frac{3\alpha\,(\alpha - 1)}{1 + 3(\alpha - 1)^2} \log_e \left\{ 1 \pm \frac{\theta}{\alpha} \left[1 + 3\,(\alpha - 1)^2\right] \right\} \quad (5)$$

where

$$\psi = \frac{(\Delta p)\,\beta}{J\rho\, C_s}$$

$$\alpha = \frac{2Q}{Vbh}$$

$$\theta = \frac{2\,\mu_1\, VL\,\beta}{J\rho\, C_s\, h^2}$$

J = Mechanical equivalent of heat

C_s = Specific heat of liquid

ρ = Density of liquid

μ_1 = Viscosity at entrance to passage

Q = Net flow

The sign convention in Equation 5 is that the upper sign corresponds to net flow to the right and the lower sign net flow to the left when referred to the situation shown in *Fig.* 1.

Equation 5 is represented in *Fig.* 2. It is quite apparent from the form of Equation 5 that a direct solution for the rate of slip flow is not obtainable, but the plotting does give a physical picture of the situation. The flow described in the upper right-hand quadrant of the plotting between $\alpha = 0$ and $\alpha = 1.0$ is particularly interesting since an instability is indicated, with two rates of flow possible for the same pressure difference in this region and a third rate possible as indicated in the upper left-hand quadrant.

The form of Equation 5 is such that a direct solution for α or the rate of flow is not possible. Since such a solution would be desirable for use in further analysis, an approximate equation was set up on the assumption that α is large compared to unity, and this equation permits direct solution for the rate of flow Q. Approximately

$$\psi = \log_e \left[1 \pm 2.5\,(\alpha - 1)\,\theta\right] \quad (6)$$

which when solved for the slip Q_{sv} yields

$$Q_{sv} = \frac{J\rho\, C_s\, bh^3}{10\,\beta\,\mu_1\, L} \left[1 - e^{\psi}\right] \quad (7)$$

The net flow and the slip flow are related by

$$Q = \frac{Vbh}{2} - Q_s \quad (8)$$

where Q_s is the flow due to pressure only and is called the slip flow.

Reference to *Fig.* 1 is made to establish this definition of slip. It is common practice to consider that the delivery of a pump at zero pressure difference

is equal to the theoretical displacement multiplied by the rotational speed. The delivery, therefore, includes the quantity $Vbh/2$ of each slip passage and the slip is, therefore, the pressure flow through the slip passage only.

These equations prove to be good approximations for large values of α and fair approximations for small values of α as shown in *Fig.* 3.

Equation 6 is useful in establishing an expression for the power loss associated with the slip passage of *Fig.* 1. The general power loss equation is simply

$$P_L = Q_s\,(\Delta p) + FV \quad (9)$$

where P_L is the power loss due to the flow through the slip passage, and F is the force that must be applied to the moving plate to maintain its motion.

From these foregoing approximations the power loss can be written

$$P_L = \frac{bh^3}{10\,\mu_1\, L}\,\frac{(e^{\psi} - 1)}{\psi}\,(\Delta p)^2 + \frac{V^2\, bL\,\mu_1\,\psi}{1.2\,h\,(e^{\psi} - 1)} \quad (10)$$

It should be noted that this equation is of the same general form as Equation 2 for the power loss with constant viscosity. If one considers all quantities constant except the clearance h, the optimum clearance h_{ov} corresponding to minimum power loss for a given set of operating conditions is

$$h_{ov} = \sqrt{\frac{\mu_1\, VL\,\psi}{0.60\,(e^{\psi} - 1)\,(\Delta p)}} \quad (11)$$

This value corresponds to a value of $\alpha - 1 = \pm 0.53$. The relationship between the optimum clearance h_{oc} with constant viscosity and the optimum clearance h_{ov} with variable viscosity is

$$\frac{h_{ov}}{h_{oc}} = 0.91\sqrt{\frac{\psi}{e^{\psi} - 1}} \quad (12)$$

This equation is later shown graphically (*Fig.* 8).

The value of h_{oc} corresponds to a value of $\alpha = 2/3$. It is significant that the order of magnitude of optimum clearance h_o for both theories is comparable and that the flow in the slip passage would be in the unstable range.

The predictions of the new theory with reference to slip are of particular interest since slip flow has received a great deal of attention by the design engineer and undoubtedly will continue to be of concern to him.

Accordingly, *Fig.* 3 has been prepared to show the relationship between slip flow with constant viscosity and slip flow with variable viscosity and all heat retained in the liquid. The slip flow for the condition of $\theta = 1$ for both slip flow to the left and slip flow to the right is shown. An interesting feature is the instability of the slip flow. At a value of ψ of approximately 0.6, the slip flow increases as indicated by the dotted line marked

"instability" with no increase in ψ, or as might be in a practical case, with no increase in pressure since ψ is directly proportional to pressure. It is also noteworthy that the slip for values of ψ greater than one is many times that indicated for constant viscosity flow. This prediction of the new theory is in accordance with observation.

For the purpose of illustrating the effect of the speed of the moving element, the clearance and the length of slip passage, plottings shown in *Fig.* 4, 5 and 6 have been prepared. In each case, the solid line represents the slip flow Q_s in gpm as a function of the clearance, velocity of moving element or length of plate, as the case may be. These curves represent the situation as calculated from the exact theory using Equation 5. The slip passage itself and the conditions of the flow are described as follows:

Velocity	$V = 20$ fps
Length of plate	$L = 0.1$ inches
Viscosity	$\mu_1 = 10{,}000$ SSU
Temperature coefficient	$\beta = 0.025$
Width of plate	$b = 1$ inch
Pressure differential	$\Delta p = 5400$ psi
Clearance	$h = 0.011$ inches

In the case of each variable, length, clearance or velocity, the variation of the slip flow as computed by Equation 5 is compared with the slip flow which would exist if the viscosity remained constant. This comparison is shown by means of the line composed of short dashes in *Figs.* 4, 5 and 6. This line passes through the design point described by the foregoing data with a velocity of 20 fps, the length of passage of 0.1-inch, and a clearance of 0.011-inch. The second dash line made up of longer dashes is asymptotic to the solid line and represents the limit of slip flow variation with the independent variable as the conditions change to make the flow approach the constant temperature situation.

In *Fig.* 4 the effect of the speed of the moving element (the moving plate of *Fig.* 1) is shown. In the case of a constant viscosity liquid, the slip would be unaffected by the speed of the moving element of the slip passage. However, real fluids are heated by the shearing forces; hence, an increase in slip with increasing speed is noted.

In *Fig.* 5 the effect of clearance on slip is shown. With a constant-viscosity liquid, the slip would vary with the third power of the clearance but with a variable viscosity, influenced by internal heat generation, the variation is with something less than the third power.

In *Fig.* 6 the effect of length of slip passage is indicated. With a constant viscosity the slip is inversely proportional to the first power of length. In the case of the heated liquid with variable viscosity, the slip does not decrease so rapidly when the length is increased beyond about 0.02-inch and shows no appreciable decrease as the length is increased beyond 0.5-inch.

Power Loss Evaluation: In order to design an

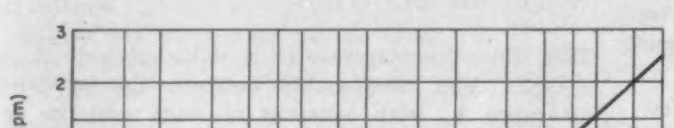


Fig. 4—Above—Representative variation of slip flow with velocity (solid line). In this graph, and in *Figs.* 5 and 6, the short-dash line represents the slip flow that would occur if viscosity remained constant. The long-dash line, asymptotic to the solid line, represents effects if the constant-temperature situation is approached

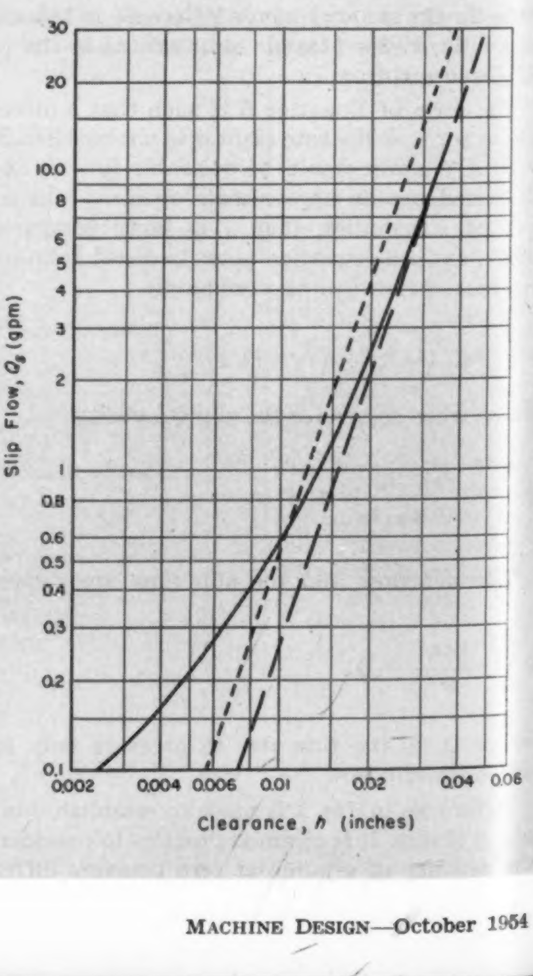


Fig. 5—Right—Representative variation of slip flow with clearance

efficient pump or motor, each slip passage must contribute as little as possible to the energy losses of the device. However, the operating conditions for the pump or motor do not remain constant; hence, it is impossible to design a unit that will perform equally well over a wide range of operating conditions. The best procedure is, therefore, to select a set of operating conditions, design to those, and then determine the effect of changes in these conditions on efficiency.

In order to facilitate this analysis, *Fig.* 7 has been prepared. The ordinate is the ratio of the power loss P_L at any clearance h to the power loss P_{Lmin} at the clearance h_o. Due to the generality of the equation for the power loss, this concept applies for both variable and constant-viscosity theories.

It is interesting to note certain facts shown in *Fig.* 7. For example, it has been general practice to use clearances smaller than are absolutely necessary. A justification for this is apparent. Consider the power loss for a clearance one-tenth of the optimum and also for a clearance ten times as large as the optimum. The smaller clearance causes a power loss 7.5 times the minimum, whereas the larger clearance results in a power loss 250 times the minimum. Conservatism and good judgment dictate using the smaller clearance. A less radical but equally significant effect is noted if the clearance is either 1/3 or 3.0 times the optimum. In these situations, the power losses are respectively, 2.3 and 7.0 times the minimum. The use of larger clearances could result in total loss of effectiveness, but the smaller clearances within

reason and feasibility can do no worse than reduce efficiency to an undesirably low figure.

The confirmation of the wisdom of small clearances by the new theory is significant. It also opens for consideration the concept of closely designed clearances when operating conditions do not vary widely or are subject to control.

Value of Clearance Design: Since the effect of clearance on performance is well established, the importance of careful design is worthy of attention. This problem will be considered in the light of the following points:

1. Effect of clearance on performance
2. Relation of optimum to design clearance
3. Difficulties in design and evaluation
4. Special conditions requiring particular attention of designer

The effect of clearance on performance is most clearly shown in *Fig.* 7. Since the greatest efficiency is obtained when the power loss of each slip passage is a minimum, the use of a clearance either larger or smaller than optimum for a given set of operating conditions will result in lower efficiency.

The relationship between design clearance and optimum clearance is controlled by production problems, range of operating conditions, and importance of high efficiency. If the cost of securing accuracy in the magnitude of clearances is greater than can be justified, then efficiency must be left to vary from one pump to another.

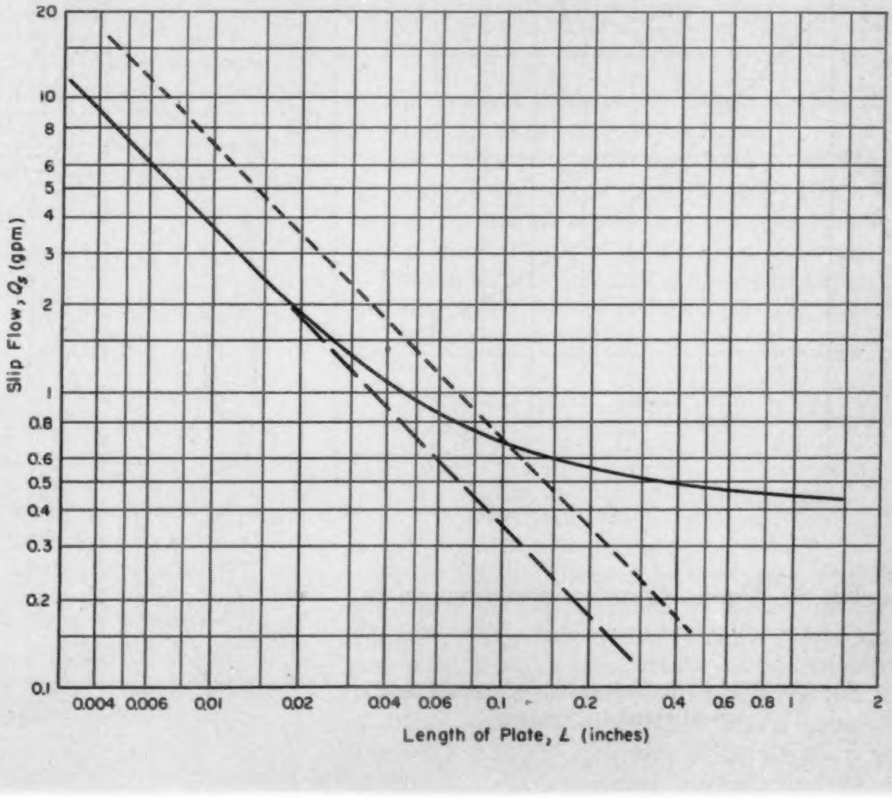


Fig. 6—Representative variation of slip flow with length

If the range of operating conditions is wide, efficiency must be sacrificed at the extremes. If operating conditions are unknown or not subject to control, good design would call for smaller than usual clearances to assure reasonable performance.

If volumetric rather than overall efficiency is a major factor, as it is in fuel pumps, very small clearances are justified since, in this case, pumping costs are usually more directly related to volume delivered than to mechanical efficiency.

Certain difficulties in design and the evalution of designs by test may be traced directly to the inadequacy of the constant-viscosity theory. For example, the process of locating serious leaks in a pump was frequently hampered by the lack of a suitable means for calculating probable values of

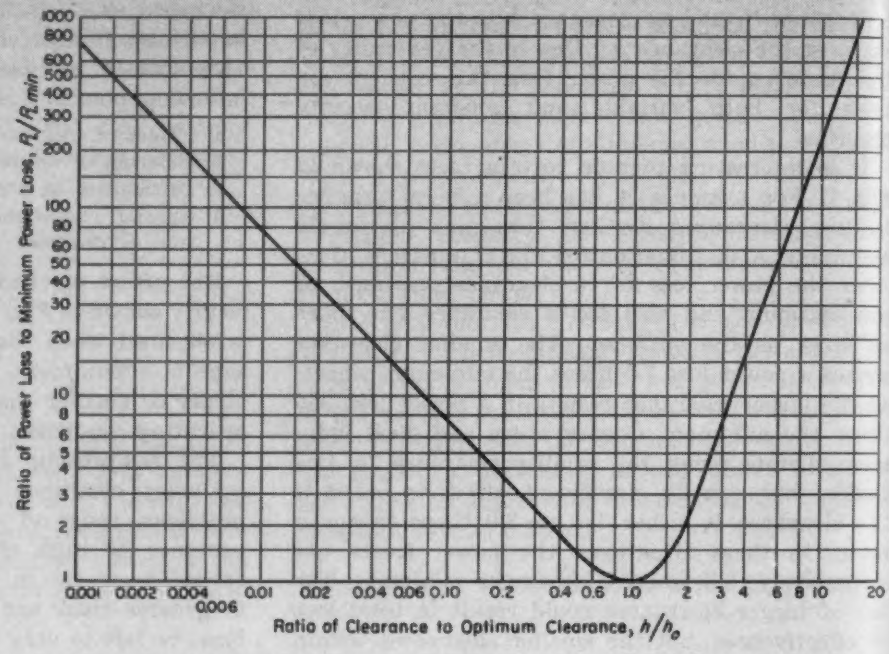


Fig. 7—Relationship of power loss to clearance

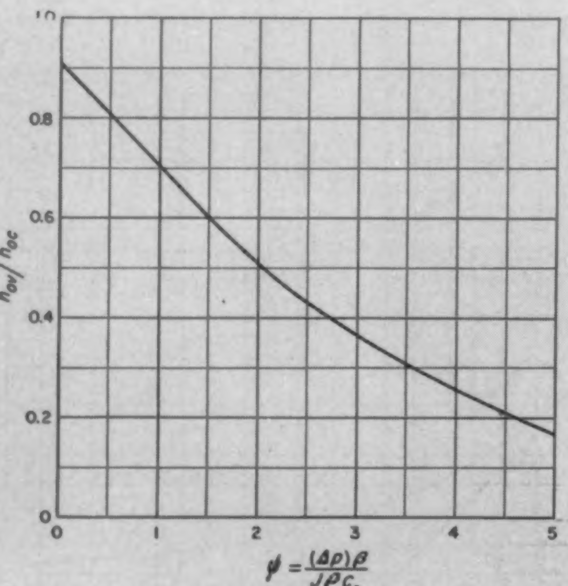


Fig. 8—Above—Clearance correction factor

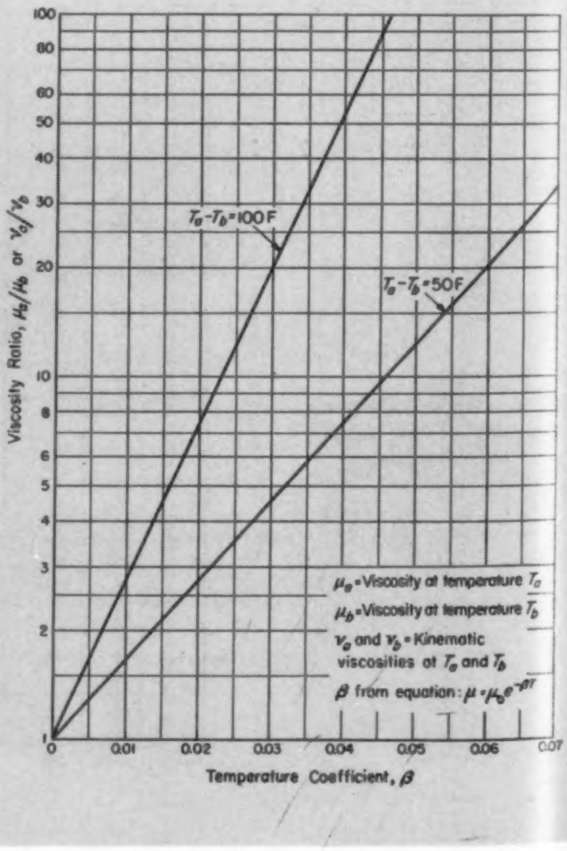


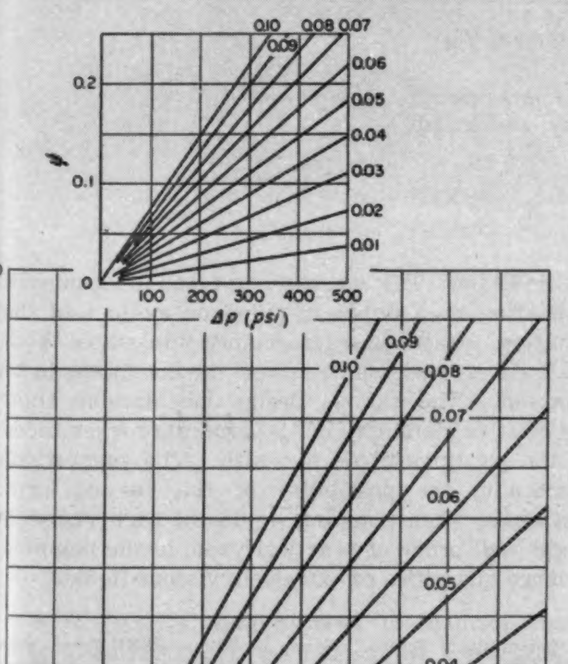
Fig. 9—Right—Relationship of temperature coefficient to viscosity

slip flow. Anomalous situations connected with the relationship between slip and speed, pressure, viscosity, and clearance could not be understood and overdesign was the natural solution.

More complete understanding of the mechanics of the flow in slip passages—concern with both slip flow and drag—cannot but assist in securing more satisfactory designs. It is to be hoped that evaluation of designs by calculation and later by test of models can be put on a rational basis through the use of the methods outlined here.

However, there remains one field of design, which was analyzed earlier[2] by the constant-viscosity method, that has received little attention by producers of pumps. This field is that of the pumping of extremely viscous liquids. The concept of the use of large clearances is still valid. It is, of course, true that a pump designed for high-viscosity liquids is absolutely useless for low-viscosity service. It is apparent that proper design of a positive-displacement pump for high-viscosity service could result in a 20 to 40 per cent reduction in pump operating costs.

Fig. 10—Parameter ψ in terms of pressure drop and temperature coefficient



Sample Design Calculation: In order to facilitate design calculations, *Figs.* 8 to 11 are included. A sample problem is worked out here illustrating the use of these charts. One should note carefully that the design charts have been prepared for the convenience of the engineer in making his calculations and are not based upon dimensionless quantities. It is necessary, therefore, to use extreme care in the use of the charts, being certain at all times that the various quantities are expressed in the proper units. Moreover, in these charts the specific heat C_s is assumed to be 0.5 btu per lb per degree F and the density of the liquid 50 lb per cu ft.

For a gear pump consider the determination of the clearance between the tip of a gear and the housing under the following circumstances:

Radius to gear tooth tip	1.5 inches
Thickness of tooth at tip	0.08 inch
Rotational speed	1800 rpm
Pressure differential	2000 psi
Number of gear teeth sealing at one time	4
Kinematic viscosity of liquid at 70 F	250 SSU
at 170 F	25 SSU
Operating temperature	70 F

In *Fig.* 9 the value of the exponent β is given as a function of viscosity and temperature. The ratio of viscosities for a 100 F difference in temperature is

$$\frac{\nu_a}{\nu_b} = \frac{250}{25} = 10$$

Reference to the chart indicates that the corresponding value of β is 0.023.

Now, since four gear teeth seal at any time, the pressure drop across each tooth is 500 psi. Reference to *Fig.* 10 shows that the appropriate value of the parameter ψ is 0.085.

The quantities VL and $\nu/\Delta p$ expressed in ft-in./sec and SSU/psi are required for the use of *Fig.* 11. They are found thus:

$$VL = \frac{1800}{60}(2\pi)\left(\frac{1.5}{12}\right)(0.08) = 1.88 \text{ ft-in./sec}$$

$$\frac{\nu}{(\Delta p)} = \frac{250}{500} = 0.5 \text{ SSU/psi}$$

From *Fig.* 11, using the two values, one obtains the value of the clearance in inches for constant viscosity flow, 7.1×10^{-4} inches. This must be corrected to take into consideration the effect of viscosity change with heating. The correction factor is obtained from *Fig.* 8. For a value of $\psi = 0.085$ the ratio of clearance with viscosity change to clearance with constant viscosity is 0.89, an al-

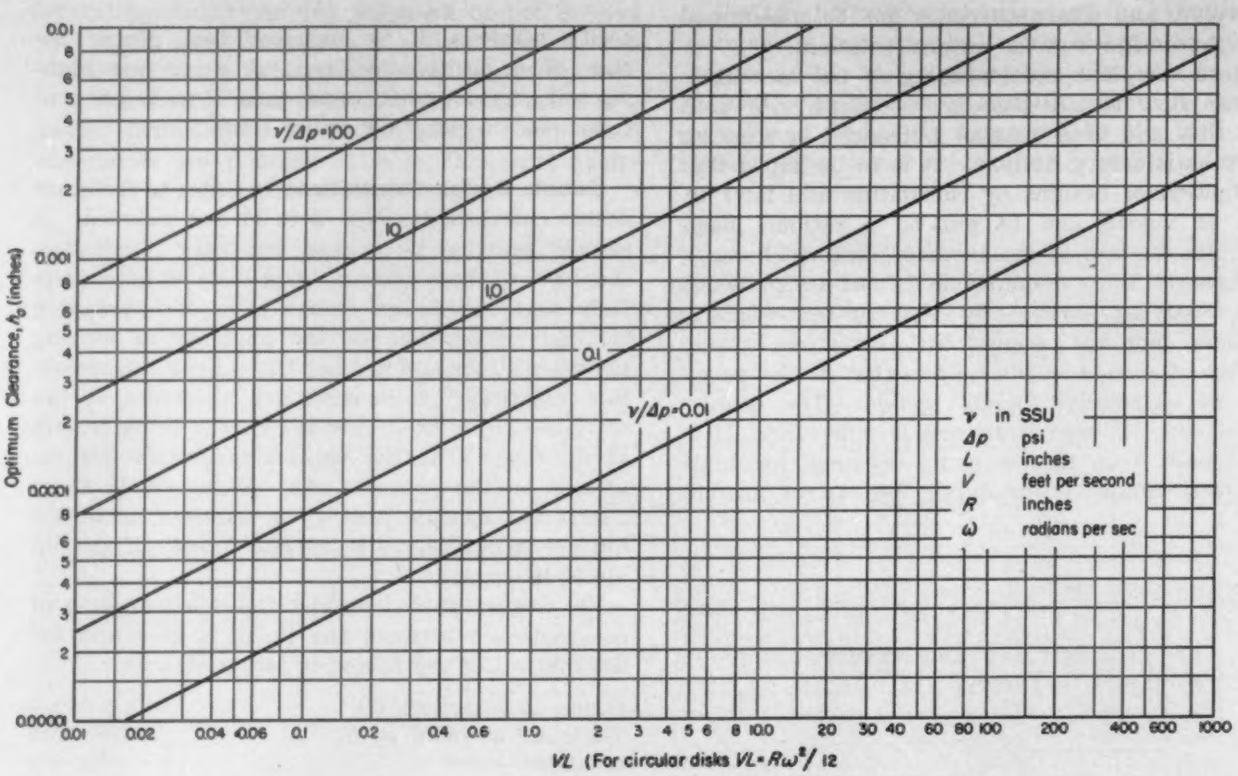


Fig. 11 — Optimum clearance in terms of viscosity, pressure drop, velocity, and length

most negligible correction calling for a clearance of 0.89 (7.1×10^{-4}) or 6.3×10^{-4} inches.

Now let us consider the design of the same gear tooth tip clearance when liquid with the following characteristics is being pumped:

Viscosity at 70 F	10000 SSU
Viscosity at 170 F	500 SSU
Operating temperature	70 F

Reference to *Fig.* 9 indicates a value of β equal to 0.0295. From *Fig.* 10 the quantity ψ is found to be 0.109.

The quantity *VL* is as before 1.88 ft-in./sec but the factor $\nu/\Delta p$ SSU/psi is now 20. Using these two numbers in connection with *Fig.* 11, the clearance with constant viscosity is found to be 0.0047-inch. The correction factor from *Fig.* 8 is 0.89, which when multiplied by the clearance 0.0047-inch, yields a figure of 0.0042-inch.

The limitations of the design charts must be kept in mind. They will give approximate results only, since the assumptions underlying the theory are at best fair approximations. However, the discussion of *Fig.* 7, showing the effect of clearance on efficiency, indicates that one has considerable latitude in the selection of the magnitude. For example, the clearance of 0.0042-inch calculated above or the previous value of 6.3×10^{-4} inch could vary by a factor of two in either direction without seriously affecting the performance.

Conclusion: The discussion of the phenomenon of heating of a liquid in pump or motor and the resulting effect on performance illustrates both qualitatively and quantitatively the conditions to be expected. The sample design calculations show the relative simplicity of the procedure when aided by the plottings given herewith. The suggestions concerning the possibility of the use of large clearances when pumping liquids of high viscosity might well prove of practical value in the pumping of large quantities of extremely viscous liquids.

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"The day has passed when we can defend our country with our hands and bodies. We all recognize that in the future we must rely increasingly on our brains. This brain power must come largely from the industrial fabric of the country because there is no other way in which we can keep it actively and gainfully employed in peacetime—so that it will be ready to serve in war if necessary." —HON. ROBERT LEBARON, *assistant to the Secretary of Defense.*

SYSTEMATIC MECHANISM DESIGN—2

How To Apply

New Symbolic Notation + Catalog of Basic Mechanisms

to the design of a mechanism for a specific function

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KINEMATIC design of a mechanism means constructing a mechanism to transform an available motion (input) into a desired motion (output) according to a specified manner. The problem statement must include information on the kind of input motion available—such as a rotation, which would be derived from a shaft—and must also give similar knowledge of the desired output end of the mechanism. The relation between input and output displacements must be given. To avoid ambiguities, the directions and points from which angular and linear displacements are measured must be indicated.

Certain mechanical features involving the spacing of the input and output parts must also be known—whether the shafts (if they are shafts) are to be parallel or whether they intersect, and if so at what angle—at any rate certain controlling dimensions or features will have to be specified.

When these features are known, and the mechanism has been studied to see during what portion of a cycle it is to be locked (if locking is required) and during what portion it is to be producing motion, each part-cycle operation can be compared with the known symbolic equations (and their implied functional relations) of the synthesized three- and four-pair mechanisms given in the *Catalog* which appeared in the previous article. From this *Catalog* the pertinent mechanisms are picked, and further study of each part-cycle operation will show not only the kinds of pair-variables that must be involved, but also their limits of operative use, i.e., their range of variation. This means a specification of when (or where) an element pair opens if a lock-unlock operation must occur, or if an intermittent drive

is needed. After each part-cycle symbolic equation has been established with its proper parameters and pair-variables, the array of equations for the complete cycle is set down in tabular form.

The parts of the mechanism are established from examination of the sequences of successive pairs. After all sequences have been considered, and thus all parts made known, the parts are assembled by bringing the pair elements into contact.

Example of Kinematic Design: Remainder of this article will comprise the statement and solution of a specific problem: to design a mechanism having the following properties:

1. Input is a shaft whose rotation is measured by θ_i
2. Output is a shaft whose rotation is measured by θ_o
3. Shafts are parallel, distance a apart
4. Value of θ_o for each value of θ_i is specified by the curve in *Fig.* 8. The curve has no discontinuity
5. The two shafts are to turn in opposite directions, as in *Fig.* 9
6. The output shaft is to be not only stationary but also locked during the straight portions of the curve of *Fig.* 8.

The specifications indicate that for continuous rotation of the input shaft the output shaft is locked for the intervals *OA, BC, DE* and *FG*, whereas the output shaft is being driven for the intervals *AB, CD, EF*, and *GH*. At *H* the cycle is completed. (A cycle of motion is defined as that interval during which all parts of a mechanism have performed one complete series of events, and are thus back at their initial positions.) The cycle is composed of two different phenomena—lock and drive—and it is therefore assumed that each will require a different mechanism.

Symbolic Equations for the Drive Intervals: The fact that the input part and output part are each a shaft requires at least one revolute for each shaft. In addition both shafts are carried in the same frame, are parallel and a distance a apart. This means that an element of each revolute is in the common frame, and hence the revolutes must occur in sequence as, for example,

$$R_n \left| \begin{array}{c} a_n \\ 0 \\ \theta_n \\ 0 \end{array} \right| R_{n+1}$$

Inspection of the *Catalog* for movable mechanisms in which such a sequence occurs discloses only three that meet the restrictions, namely,

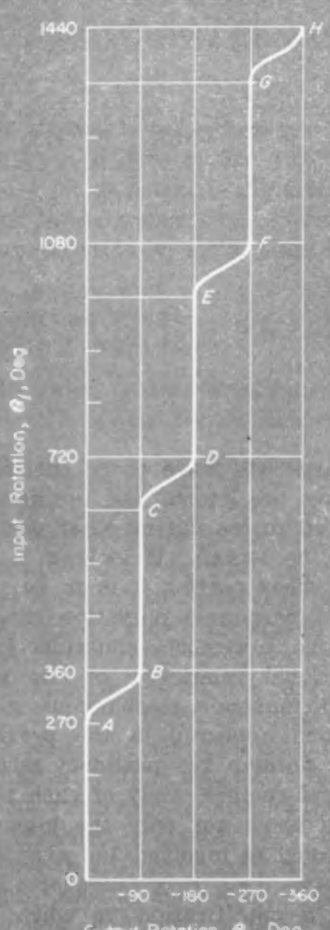


Fig. 8—Left—Desired relationship between input and output motions for problem example

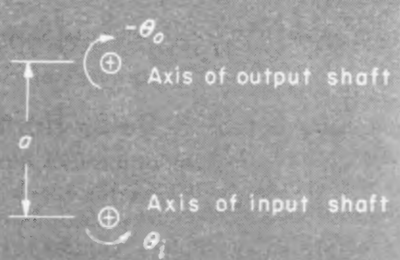
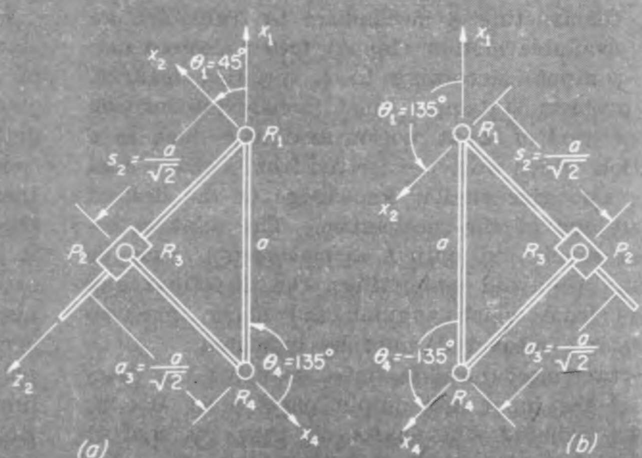


Fig. 9—Above—Sign convention for input and output shaft rotation in problem example

Fig. 10—Below—Drive mechanism at dead points. Position at points *A, C, E*, and *G* is shown at *a*; position at points *B, D, F*, and *H* is shown at *b*



items 14, 15 and 17, whose equations are:

$$R_1\left|\begin{matrix}a_1\\0\\\theta_1\\0\end{matrix}\right| R_2\left|\begin{matrix}a_2\\0\\\theta_2\\0\end{matrix}\right| R_3\left|\begin{matrix}a_3\\0\\\theta_3\\0\end{matrix}\right| R_4\left|\begin{matrix}a_4\\0\\\theta_4\\0\end{matrix}\right| = 1 \quad\ldots\ldots\ldots(1)$$

$$R_1\left|\begin{matrix}0\\90\\\theta_1\\0\end{matrix}\right| P_2\left|\begin{matrix}a_2\\90\\0\\s_2\end{matrix}\right| R_3\left|\begin{matrix}a_3\\0\\\theta_3\\0\end{matrix}\right| R_4\left|\begin{matrix}a_4\\0\\\theta_4\\0\end{matrix}\right| = 1 \quad\ldots\ldots\ldots(2)$$

$$P_1\left|\begin{matrix}0\\a_1\\90\\s_1\end{matrix}\right| P_2\left|\begin{matrix}a_2\\90\\90\\s_2\end{matrix}\right| R_3\left|\begin{matrix}a_3\\0\\\theta_3\\0\end{matrix}\right| R_4\left|\begin{matrix}0\\90\\\theta_4\\0\end{matrix}\right| = 1 \quad\ldots\ldots\ldots(3)$$

Equation 1 shows four sequences, Equation 2 shows two sequences, and Equation 3 only one. There is only one parameter a available, however, which might be assigned to a_4 of Equations 1 and 2 and a_3 of Equation 3. One of the associated revolutes then represents the input shaft, and the other the output shaft. Procedure will be to investigate the simpler cases, Equations 2 and 3, with the hope that they can meet the specifications. If not, Equation 1, whose additional parameter might be useful, will be investigated.

A specification is that the curve must have no discontinuities at A and B, i.e., $d\theta_o/d\theta_i = 0$ at these points. At A, $\theta_i = 270$ degrees, $\theta_o = 0$ degrees; at B, $\theta_i = 360$ degrees, $\theta_o = -90$ degrees. Likewise, no discontinuities are to exist at C, D, etc., described by intervals of 360 degrees in θ_i. Examination of the functional relations of Equation 3 (see *Catalog*, item 17) shows that $\theta_4 = -\alpha - \theta_3$, which is a linear relation giving no zero derivative. Since θ_i is linearly related to θ_3 and θ_o is also linearly related to θ_4, the necessary zero derivative is absent; hence Equation 3 is out.

For Equation 2 the functional relations (see *Catalog*, item 15) are

$$\theta_1 = \cos^{-1}\left[\frac{a_2 + a_3\cos\theta_3}{a_4}\right] \text{ and}$$

$$\theta_1 + \theta_3 + \theta_4 = 180^\circ$$

Inasmuch as a zero derivative between θ_o and θ_i must occur at points A and B (90-degree interval in both θ_o and θ_i), it is necessary to find two angles θ of the Equation 2 mechanism that also possess this property. Such a relation exists between θ_1 and θ_4. From the *Catalog*, item 15,

$$\frac{d\theta_4}{d\theta_1} = -\frac{a_4\sin\theta_1}{\sqrt{a_3^2 - (a_2 - a_4\cos\theta_1)^2}} - 1$$

The derivative $d\theta_i/d\theta_4$ is zero when its inverse $d\theta_4/d\theta_i$ is infinite. This is true when

$$a_3^2 - (a_2 - a_4\cos\theta_1)^2 = 0 \text{ or}$$

$$\theta_1 = \cos^{-1}\frac{a_2 \pm a_3}{a_4}$$

Two values of θ_1 meet this condition; R_1 is as-

sociated with the output shaft and R_4 with the input shaft.

At this time three parameters a_2, a_3 and a_4 have appeared. The parameter a_4 was used to meet the shaft distance specification. A second specification was given by requiring a zero derivative at specific points. Had there been a third specification on the curve, then a_2 would have been the parameter needed to meet that. Had there been a fourth specification, then a four-parameter mechanism like Equation 1 would have had to be employed. Since there are three parameters but only two specifications, one parameter is of arbitrary value; it can be set equal to zero for simplicity. With $a_3 = 0$, the mechanism becomes

$$R_1\left|\begin{matrix}0\\90\\\theta_1\\0\end{matrix}\right| P_2\left|\begin{matrix}a_2\\90\\0\\s_2\end{matrix}\right| R_3\left|\begin{matrix}0\\0\\\theta_3\\0\end{matrix}\right| R_4\left|\begin{matrix}a_4\\0\\\theta_4\\0\end{matrix}\right| = 1$$

It will be noted that R_3 and R_4 are concentric revolutes. This special situation was discussed under *Criterion of Movability* in the previous article, where it was shown that two concentric revolutes are equivalent to a single revolute having the same axis. The *Catalog* shows that the resulting mechanism is immovable and hence cannot be used for a drive. However, if $a_2 = \theta$, then the resulting mechanism is still movable, i.e., capable of performing as a drive mechanism. Hence $d\theta_1/d\theta_4 = 0$ for $\theta_1 = \cos^{-1}(\pm a_3/a_4)$. These two values have to be at a 90 degree interval; this will be realized if $a_3 = a_4/\sqrt{2}$, then $d\theta_1/d\theta_4 = 0$ for $\theta_1 = \cos^{-1}(\pm 1/\sqrt{2}) = 45$ degrees and 135 degrees. For both values of zero derivative (dead points) the mechanism is shown on ***Fig.*** 10.

It is now necessary to establish the relations between θ_i and θ_4 and between θ_o and θ_1. From the *Catalog*, it is possible to derive the relation

$$\theta_4 = \cos^{-1}[-\sqrt{2}\cos\theta_1] - \theta_1$$

which makes it possible to deduce the values of θ_4 for the positions A and B. Those values together with the corresponding values of θ_1, θ_i and θ_o are shown in the following table:

	θ_i	θ_4	θ_o	θ_1
A	270	135	0	45
B	360	−135	−90	135

From this table the following two relations are found: $\theta_4 = \theta_i - 135$ degrees, and $\theta_1 = -\theta_o + 45$ degrees.

The curve specifies that for $0 < \theta_i < 270$ the value of θ_o remains zero (no drive) and that for $270 < \theta_i < 360$ the value θ_o goes from 0 to -90 degrees (drive). At $\theta_i = 360$ degrees (point B) the no-drive condition starts again, etc. In other words, the driving mechanism must be open (no drive) over the interval $0 < \theta_i < 270$ and closed (drive) for $270 < \theta_i < 360$. The mechanism must

open again at $\theta_i = 360$ degrees (point B).

Since the mechanism has to be closed and open for certain discrete intervals, it means that one of its pairs has to be open periodically, i.e., its elements taken out of contact with each other. Obviously, the revolutes R_4 and R_1 connecting the input and output shafts to the frame should remain complete; thus a decision must be reached as to whether R_3 or P_2 is to be opened. From a practical standpoint an incomplete revolute is perhaps more difficult to fashion than an incomplete prism, for an open prism results on separating slider and guide.

Referring to the *Catalog*, and substituting $a_4 = a$ and $a_3 = a/\sqrt{2}$, we have $s_2 = \sqrt{(a^2/2) - a^2\cos^2\theta_1} + a \sin \theta_1$. When $\theta_i = 270$ degrees then $\theta_1 = 45$ degrees whence $s_2 = a/\sqrt{2}$. When $\theta_i = 360$ degrees then $\theta_1 = 135$ degrees whence $s_2 = a/\sqrt{2}$. Since the mechanism is to remain closed for the interval $270 < \theta_i < 360$, the prism elements will be in contact as long as $s_2 < a/\sqrt{2}$, and will be separated when $s_2 \geqq a/\sqrt{2}$ (open mechanism).

It is now possible to write the symbolic equation in which all of the parameters have been evaluated:

$$R_1 \begin{vmatrix} 0 \\ 90 \\ \theta_o + 45 \\ 0 \end{vmatrix} P_2 \begin{vmatrix} 0 \\ 90 \\ 0 \\ s_2 \end{vmatrix} R_3 \begin{vmatrix} a/\sqrt{2} \\ 0 \\ \theta_3 \\ 0 \end{vmatrix} R_4 \begin{vmatrix} a \\ 0 \\ \theta_i - 135 \\ 0 \end{vmatrix} = 1$$

It is true when $s_2 < a/\sqrt{2}$. This equation defines that part of the complete mechanism that will operate (drive) over the interval AB. During this interval it will maintain the originally specified relation between θ_i and θ_o. The pair-variables s_2 and θ_3 will also have definite values for all values of θ_i, but they are of no direct interest.

For the intervals CD, EF, and GH, similar symbolic equations apply. They are obtained by replacing θ_o by $\theta_o - 90$, $\theta_o - 180$ and $\theta_o - 270$.

It has been seen that two revolutes must appear in a sequence such as

$$R_n \begin{vmatrix} a_n \\ 0 \\ \theta_n \\ 0 \end{vmatrix} R_{n+1}$$

As with the driving mechanism, these revolutes connect the input and output shafts to the frame and consequently have the same axes as the former R_4 and R_1.

A search of the *Catalog* for locked mechanisms in which such a sequence occurs discloses only one:

$$R_1' \begin{vmatrix} a \\ 0 \\ \theta_1' \\ 0 \end{vmatrix} R_2' \begin{vmatrix} 0 \\ 0 \\ \theta_2' \\ 0 \end{vmatrix} R_3' \begin{vmatrix} a \\ 0 \\ \theta_3' \\ 0 \end{vmatrix} = 1$$

The parameter a is directly known since it was a specification. This mechanism must be closed (locked) in the interval OA and open (unlocked) in the interval AB.. To obtain this effect, one of the pairs has to be incomplete. Inasmuch as R_3' and R_1' connect the input and the output shafts to the frame they must remain complete: thus R_2' must be the pair of opening or disconnection.

One way of constructing the incomplete revolute R_2' (which is coaxial with R_3' of the input shaft) is shown in *Fig.* 11*a*. The axes x_1', x_2' and x_3' are placed according to the convention. The functional relations from the *Catalog* become $\theta_2' + \theta_3' = 180$ degrees and $\theta_1' = 180$ degrees. The angles ϕ and ψ shown in *Fig.* 11 define the angular limits of the revolute element $R_2'+$. As shown in *Fig.* 11*a* and *b*, the mechanism will be locked if $180 - \psi < \theta_2' < 180 + \phi$. The value of the angle γ is seen to be unimportant.

Since the revolutes R_2' and R_3' are coaxial, the origin of θ_3' is arbitrary and its value with respect

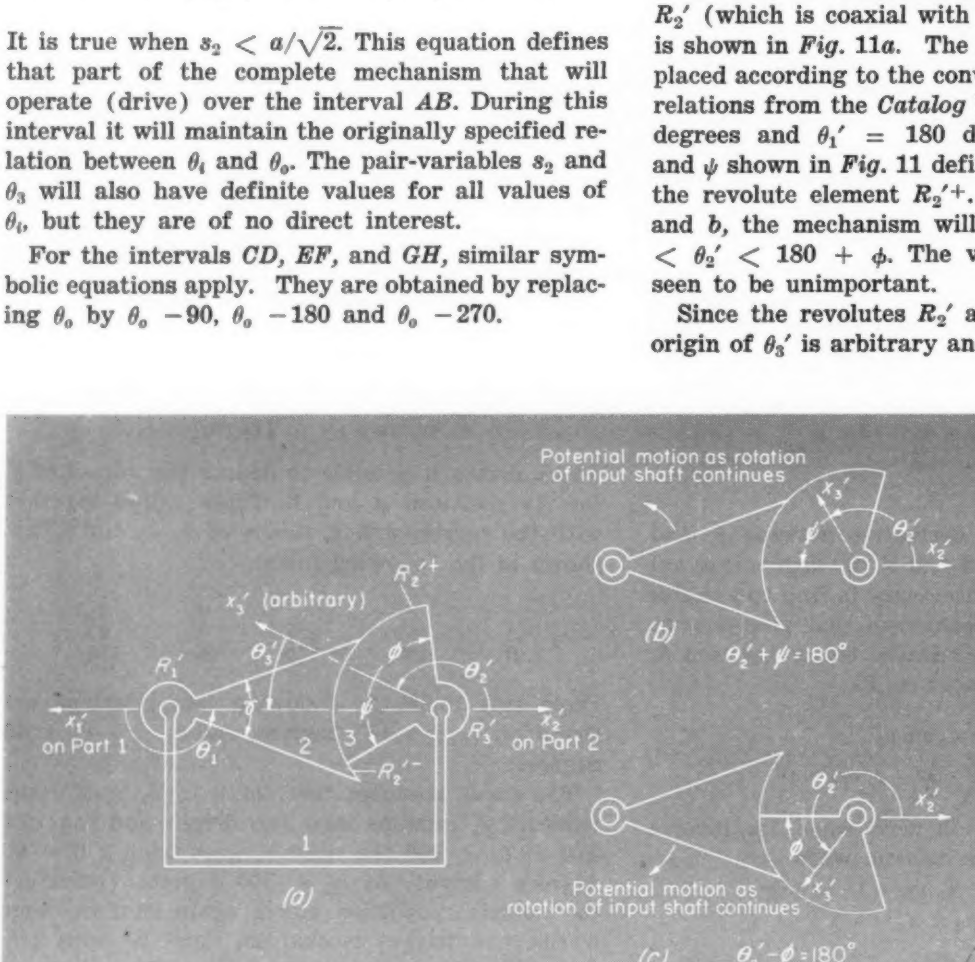


Fig. 11—Lock mechanism for problem example. Sketches *b* and *c* establish limits of input shaft rotation within which output shaft is locked

mechanism, or $\theta_3' = \theta_i - 135$. From the functional properties of the mechanism it is known that $\theta_1' = 180$ degrees; and since θ_o is held to zero during the action period of the mechanism, $\theta_o = \theta_1' - 180$ or $\theta_1' = \theta_o + 180$.

This mechanism is to be closed over the interval $0 < \theta_i < 270$ and open for $270 < \theta_i < 360$. From the functional relations, $\theta_2' = 180 - \theta_3'$ and $\theta_3' = \theta_i - 135$, from which $\theta_2' = 315 - \theta_i$. When $\theta_i = 0$, $\theta_2' = 315$; for $\theta_i = 270$, $\theta_2' = 45$; this then is the interval during which the elements of R_2' are in contact and the mechanism is closed.

Now the complete symbolic equation is:

$$R_1 \left| \begin{matrix} a \\ 0 \\ \theta_o+180 \\ 0 \end{matrix} \right| R_2' \left| \begin{matrix} 0 \\ 0 \\ \theta_2' \\ 0 \end{matrix} \right| R_4 \left| \begin{matrix} a \\ 0 \\ \theta_i-135 \\ 0 \end{matrix} \right| = 1$$

which is true when $45 < \theta_2' < 315$. Comparing this with the inequality deduced from *Fig.* 11, $\psi = 135$ and $\phi = 135$. The foregoing symbolic equation defines the mechanism that will operate as a lock (no possible rotation of the output shaft) during the interval OA.

For the intervals BC, DE, and FG similar symbolic equations apply; they are obtained by replacing θ_o by $\theta_o - 90$, $\theta_o - 180$ and $\theta_o - 270$.

Block Diagram Interpretation: In *Fig.* 12 the symbolic equations are written opposite the intervals to which they apply. Each of the eight equations was derived from a mechanism which appeared in the *Catalog*; there are then eight synthesized mechanisms composing the whole mechanism. By reason of common elements, portions of several of the synthesized mechanisms can be combined on a single piece of metal.

It has been seen that a closed mechanism may be represented by either a symbolic equation or a block diagram of the type of *Fig.* 7 in the previous article. The eight block diagrams that are equivalent to the array of eight symbolic equations describing the complete mechanism are shown in *Fig.* 13; the mechanisms have been grouped as *drive* mechanisms and *locking* mechanisms. This grouping shows directly the existence of similar

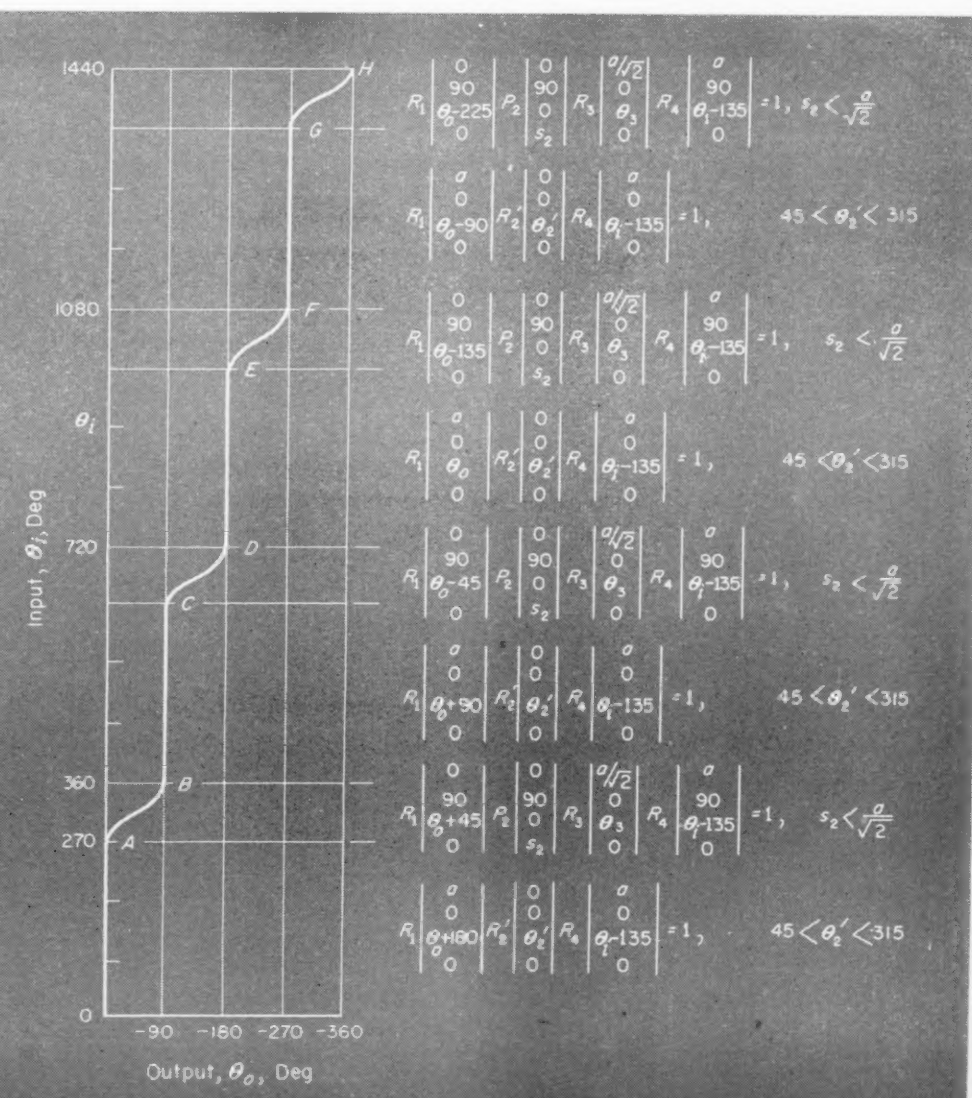


Fig. 12—Description of mechanism by an array of symbolic equations

elements in the various machine parts. On a given machine part the assignment of the positive or negative elements is arbitrary, for the positive and negative elements may be interchanged. It is observed that the blocks representing each machine part on the diagram, *Fig.* 13, form four columns.

All the blocks of the first column contain the pair element R_4^+. The position of R_4^+ is described with respect to R_3^+ in the first four blocks, and with respect to $R_2'^+$ in the last four blocks. The pair elements R_3^+, $R_2'^+$ and R_4^+ therefore lie on the same machine part, represented in *Fig.* 14 by the Block 1.

All the blocks of the second column contain the pair elements R_4^- and R_1^-. These two pair elements therefore lie on the same machine part, represented in *Fig.* 14 by Block 2.

All the blocks of the third column contain the pair elements R_1^+, with respect to which the positions of four prism-elements P_2^- and four revolute-elements $R_2'^-$ are described. All these pair elements therefore lie on the same machine part, represented in *Fig.* 14 by Block 3.

All the blocks of the fourth column contain P_2^+ and R_3^-. These two pair elements therefore lie on the same machine part represented in *Fig.* 14 by Block 4.

Each of the Blocks of *Fig.* 14 now represents one machine part of the complete mechanism. It must be emphasized that the complete mechanism is always in a state of closure: when the lock mechanisms are open, one of the drive mechanisms is closed; and when the drive mechanisms are open, one of the lock mechanisms is closed. In *Fig.* 14 the solid line *fg* shows the lock mechanism for *FG* as closed; all the other mechanisms are open, but their potentials of closure are shown by broken lines.

This *Fig.* 14 is the ultimate that the indirect synthesis can give. All necessary pairs have been

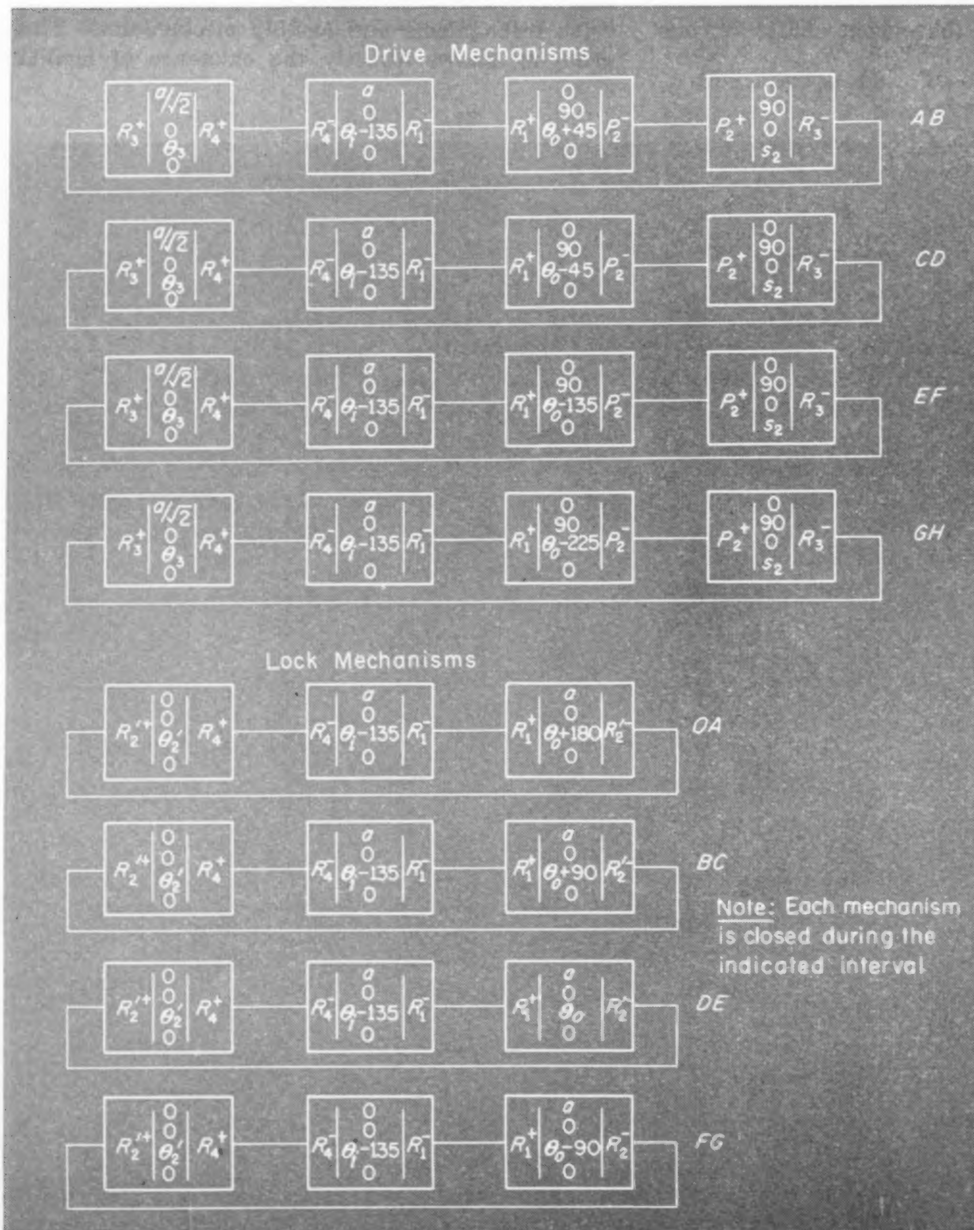


Fig. 13—Block diagrams of the eight synthesized mechanisms, grouped to show similar elements

defined in terms of their axes and pair-variables. The details of the construction of the pairs are not given by this indirect synthesis; for example, this indirect synthesis cannot tell the bearing form that a revolute might take, as a journal, ball, roller, pivot bearing. Neither are the diameters or other bearing dimensions indicated. Similarly, constructional details for the prisms are subject to the individual designer's choice.

Machine Part Design: The problem is now to interpret each of the Blocks as a machine part. The actual form of the part might be realized in different ways; the forms shown in the following represent only one way.

Block 1, *Fig.* 15. First, at the upper left corner of the diagram, *Fig.* 15*a*, is R_3^+, located by its axis z_3. Further, R_4^+ is shown related to R_3^+ by the perpendicular distance $a/\sqrt{2}$, *Fig.* 15*b*. Now the z_4-axis and its revolute can be located. The axial distance between R_4^+ and $R_2'^+$ is seen to be zero, i.e., R_4^+ and $R_2'^+$ are coaxial. As shown by the broken line between $R_2'^-$ of Block 3 (*Fig.* 14) and $R_2'^+$, the revolute element $R_2'^+$ is incomplete. The angular limits of the incomplete revolute element $R_2'^+$ are established by $\psi = 135$ degrees and $\phi = 135$ degrees, as shown on *Fig.* 11. The actual mechanical equivalent of Block 1 is shown in *Fig.* 15*b*.

Block 2, *Fig.* 16. The diagram, *Fig.* 16*a*, indi-

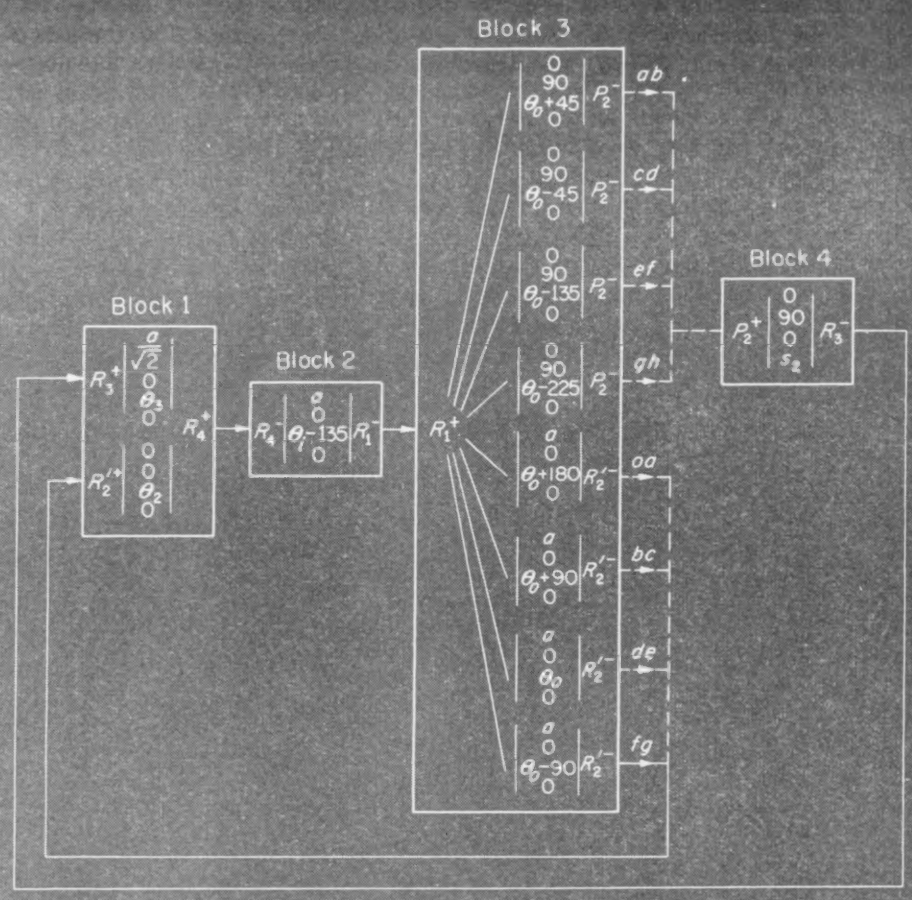


Fig. 14—Block diagram showing the four parts formed by combining common parts of the eight synthesized mechanisms of *Fig.* 13

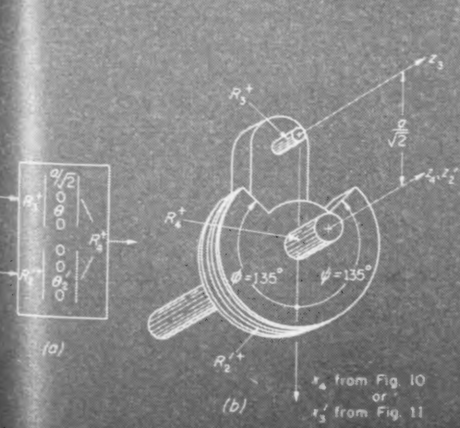


Fig. 15—Left—Block 1 (*a*) and its interpretation (*b*)

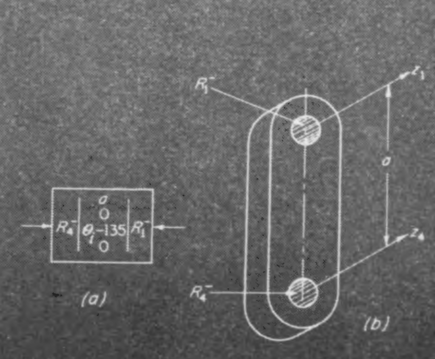


Fig. 16 — Right — Block 2 (*a*) and its interpretation (*b*)

cates two negative revolute elements a distance a apart. This part is the frame, *Fig.* 16*b*, since these negative elements provide for the support of the input and output shafts.

Block 3, *Fig.* 17. A first inspection of the diagram, *Fig.* 17*a*, shows that this block is connected to Block 2 by the revolute element R_1^+, that it carries four incomplete prism elements P_2^-, and also four incomplete revolute elements $R_2'^-$. The z-axes of the prism elements are at 90 degrees to those of all the revolutes. The shape of this block is established in detail by considering the meaning of each of the parameters.

The revolute element R_1^+ has a co-ordinate system $x_1^+y_1^+z_1^+$ as shown in *Fig.* 17*b*. The block diagram data are interpreted on the basis of this co-ordinate system.

The element P_2^- for ab is related to the pair R_1 by the four parameters $a = 0$, $\alpha = 90$ degrees, $\theta = \theta_o + 45$ degrees, $s = 0$. Since $a = 0$ and $s = 0$, the z_2-axis of P_2^- (ab) goes through the origin of the system $x_1^+y_1^+z_1^+$, *Fig.* 17*c*. With $\alpha = 90$ degrees, this z_2-axis is perpendicular to the axis z^+_1, and hence lies in the plane $x_1^+y_1^+$. The x_2-axis of $P_2^-(ab)$, which by definition is perpendicular to z_1 and z_2, then also lies in the plane $x_1^+y_1^+$, with $\theta = \theta_o + 45$ degrees. This x_2-axis is at $+45$ degrees to the x_1^+-axis. The z_2-axis is therefore at $+45 + 90 = +135$ degrees from the x_1^+-axis in the $x_1^+y_1^+$-plane.

The element $P_2^-(cd)$ is related to the pair R_1 in a manner similar to the foregoing. Its x_2-axis lies in the $x_1^+y_1^+$-plane at -45 degrees to the x_1^+-axis; this locates the z_2-axis at $-45 + 90 = 45$ degrees. The z_2-axes of the remaining two P_2^- elements are located at -45 and -135 degrees from the x_1^+-axis.

On the element $R_2'^-(oa)$, *Fig.* 17*d*, it is found that $a = 0$, $\alpha = 0$, $\theta = \theta_o + 180$ degrees and $s = 0$. Since $\alpha = 0$, the z'_2-axis of $R'_2(oa)$ is parallel to z_1^+; with $s = 0$, the axis x'_2 of $R_2'^-$ lies in the plane $x_1^+y_1^+$, and with $\theta = \theta_o + 180$ degrees, x_2' makes

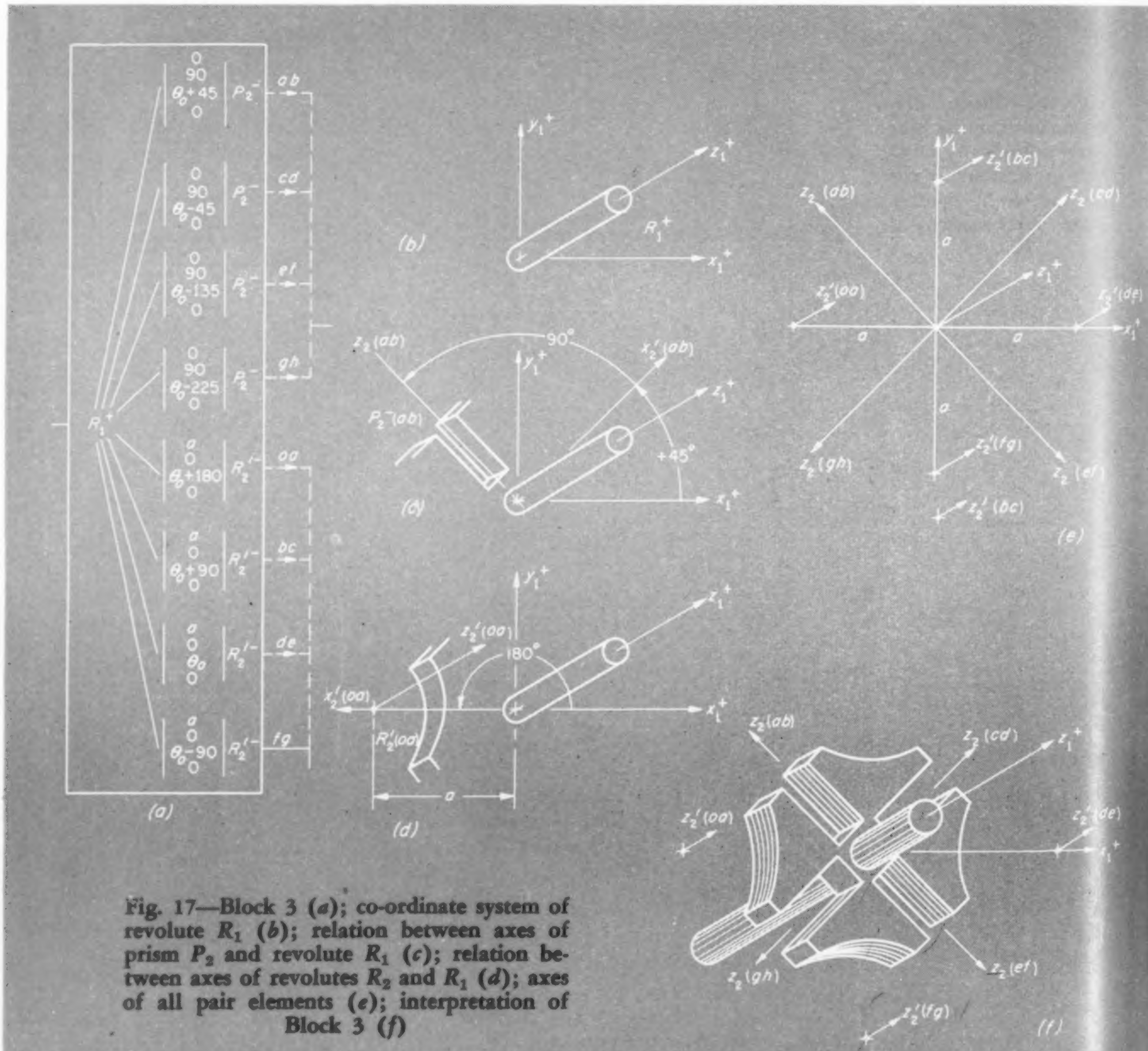


Fig. 17—Block 3 (*a*); co-ordinate system of revolute R_1 (*b*); relation between axes of prism P_2 and revolute R_1 (*c*); relation between axes of revolutes R_2 and R_1 (*d*); axes of all pair elements (*e*); interpretation of Block 3 (*f*)

an angle of 180 degrees with x_1. The origin of the pair element $R_2'(oa)$ is on this x_2'-axis at a distance a from the origin of R_1.

The element $R_2'^{-}(bc)$ is related to the pair R_1 in a manner similar to the foregoing. Its z_2'-axis is parallel to z_1, its x_2'-axis lies in the plane $x_1^+y_1^+$, and makes an angle of 90 degrees with x_1^+. The origin of the pair $R_2'^{-}(bc)$ is on this x_2'-axis at the distance a from the origin of R_1. The origins of the remaining two $R_2'^{-}$ elements are located at distances a from the origin of R_1 and at 90-degree intervals.

The axes of all the pair elements have now been established, *Fig.* 17*e*. The actual dimensions of the pair elements are not defined by kinematics; they depend upon other factors including practical expediency, strength, wear resistance, etc. One way of making the part is shown in *Fig.* 17*f*, where the slots represent the negative prism elements, with h^- being the distance from the origin of R_1 to the slot-end where disconnection takes place. The cut-out corners represent the incomplete revolute elements $R_2'^{-}$. Their radius is equal to the radius of $R_2'^{+}$ shown in *Fig.* 15.

Block 4, *Fig.* 18. The diagram indicates an incomplete prism element P_2^+ and a revolute element R_3^-, related by the parameters $a = 0$, $\alpha = 90$ degrees, $\theta = 0$ and $s = s_2$. Of these, s_2 is the pair-variable of the prism which, since $\alpha = 90$ degrees, is at right angles to the revolute.

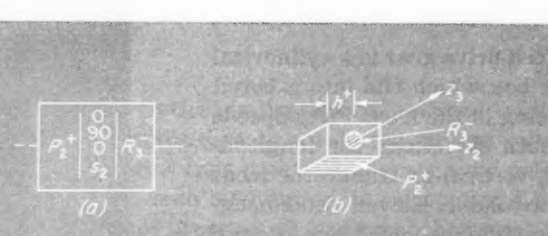
The revolute element R_3^- fits the R_3^+ element of

Block 1, *Fig.* 15*b*, and the prism element P_2^+ must fit the P_2^- elements of *Fig.* 17*f*. The distance between the origin of the revolute R_3 and the end of the prism element where disconnection takes place is h^+. Between h^+ and h^- (defined previously) there is the relation $h^+ + h^- = a/\sqrt{2}$, which reflects the fact that the pair P_2 is disconnected when $s_2 > a/\sqrt{2}$. Now that all the parts of the mechanism are known, they may be assembled as shown in *Fig.* 19.

It should be noted that a practical difficulty would exist in lining up the P_2^+ element for insertion into the P_2^- elements. This difficulty may be avoided by substituting a higher pair for the prism-revolute combination in the manner shown in *Fig.* 3. The higher pair, formed in part from a circular pin, will have the same "axis" as R_3. Since engagement is made when the axis of the pin is just at the end of the slot, it is seen that $h^+ = 0$, giving $h^- = a/\sqrt{2}$. The mechanism resulting from this modification is shown in *Fig.* 20.

The mechanism of *Fig.* 20 is well known to horologists, motion picture equipment designers, and machine tool designers as one form of the Geneva Stop. In the literature of Continental Europe this particular form is called the Maltese Cross. The intermittent motion feature is used in some clocks, for film drives, and tool or work-piece positioning.

Fig. 18—Block 4 (*a*); and its interpretation (*b*)



ig. 19 — Complete
chanism, combining
gs. 15, 16, 17, and
8, with lower pairs
urface contact) only

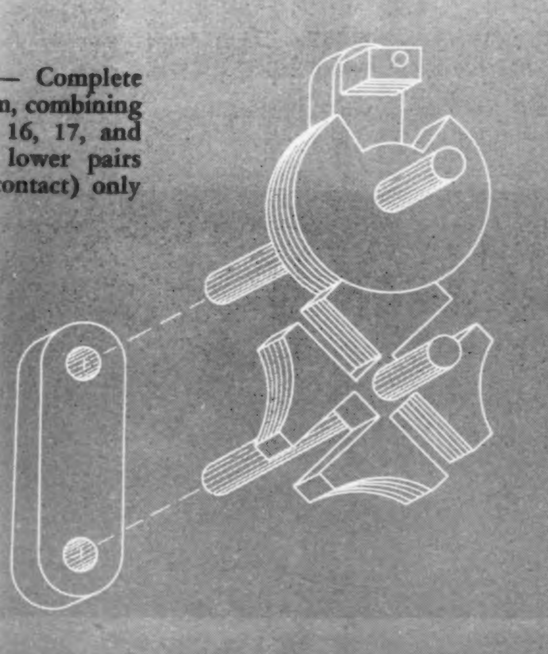
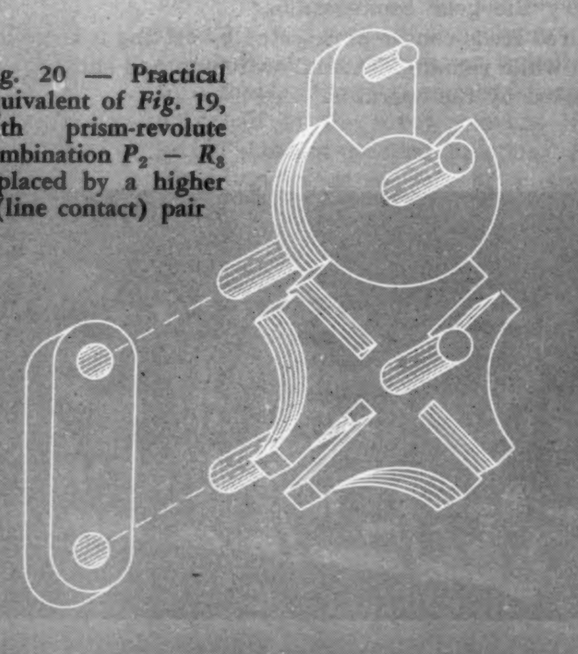
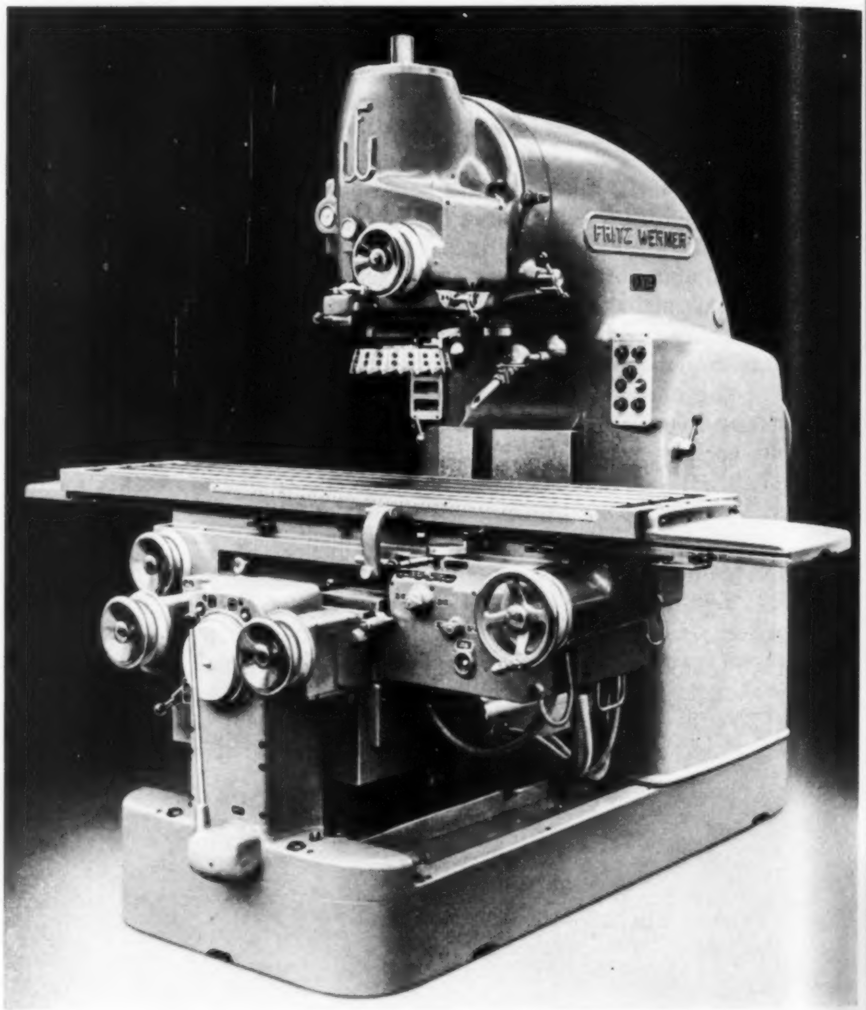


Fig. 20 — Practical equivalent of *Fig.* 19, with prism-revolute combination $P_2 - R_3$ replaced by a higher (line contact) pair

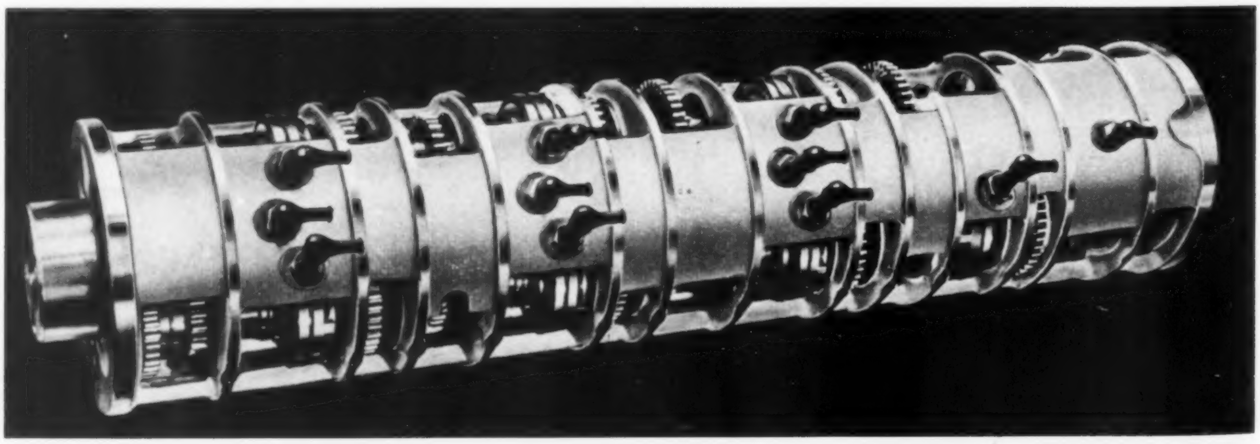


Milling Machine Drive Combines

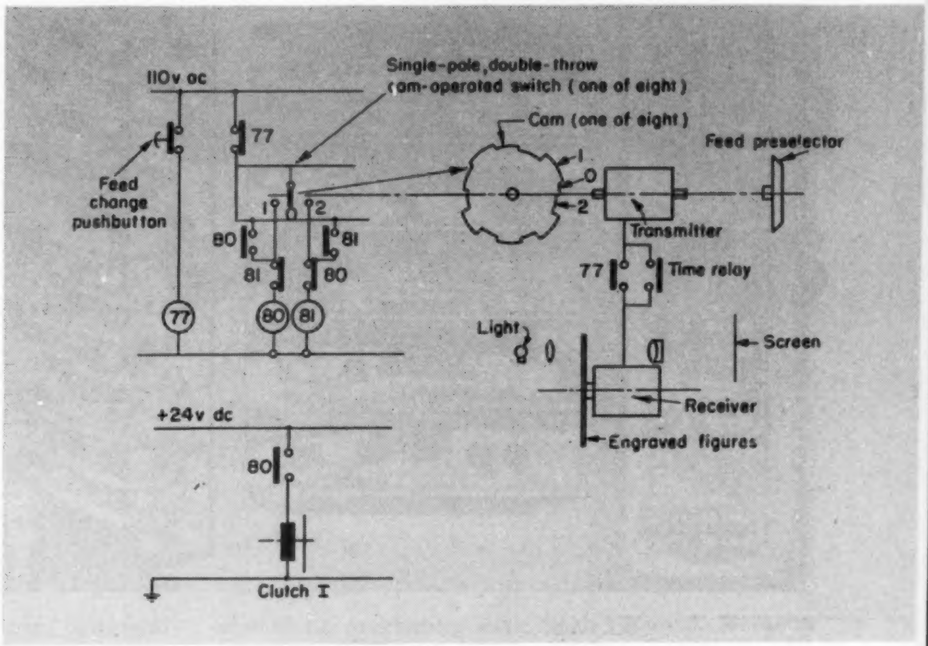
PRESELECTION of 42 spindle speeds from 16 to 1800 rpm and feeds from $\frac{1}{4}$ to 80 inches per minute; electrohydraulic and electromagnetic controls, and electro-optical indication of selected speeds and feeds are among the features of a vertical milling machine produced by Fritz Werner Aktiengesellschaft of Berlin and sold in this country by Marac Machinery Corp. Powered by a 40-horsepower motor, the machine weighs approximately 25,000 pounds and measures approximately 10 by 8 by 10 feet high.



Feed drive gear is a cylindrical gear box which fits into a bored housing in the knee. Fifty speeds in both directions for longitudinal, vertical or transverse feeds are available. Eleven electromagnetic clutches which are integral parts of the gear box are used to vary the gear combinations. Required feeds can be preselected by setting a large dial on the front of the machine while running. Actual switching and shifting is performed when a button is pushed by the operator.

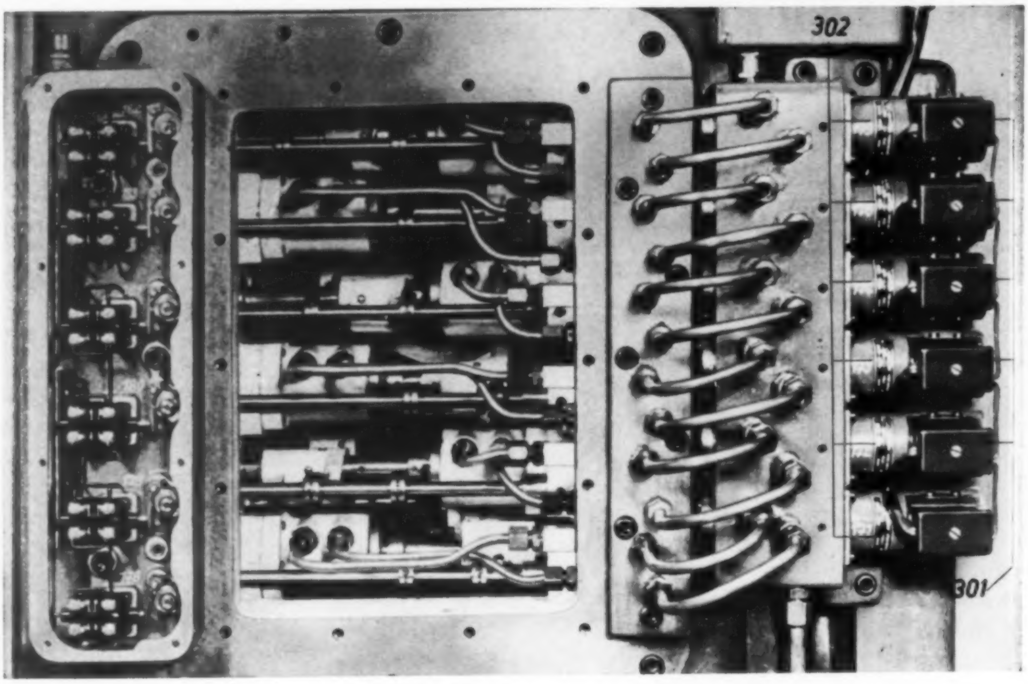


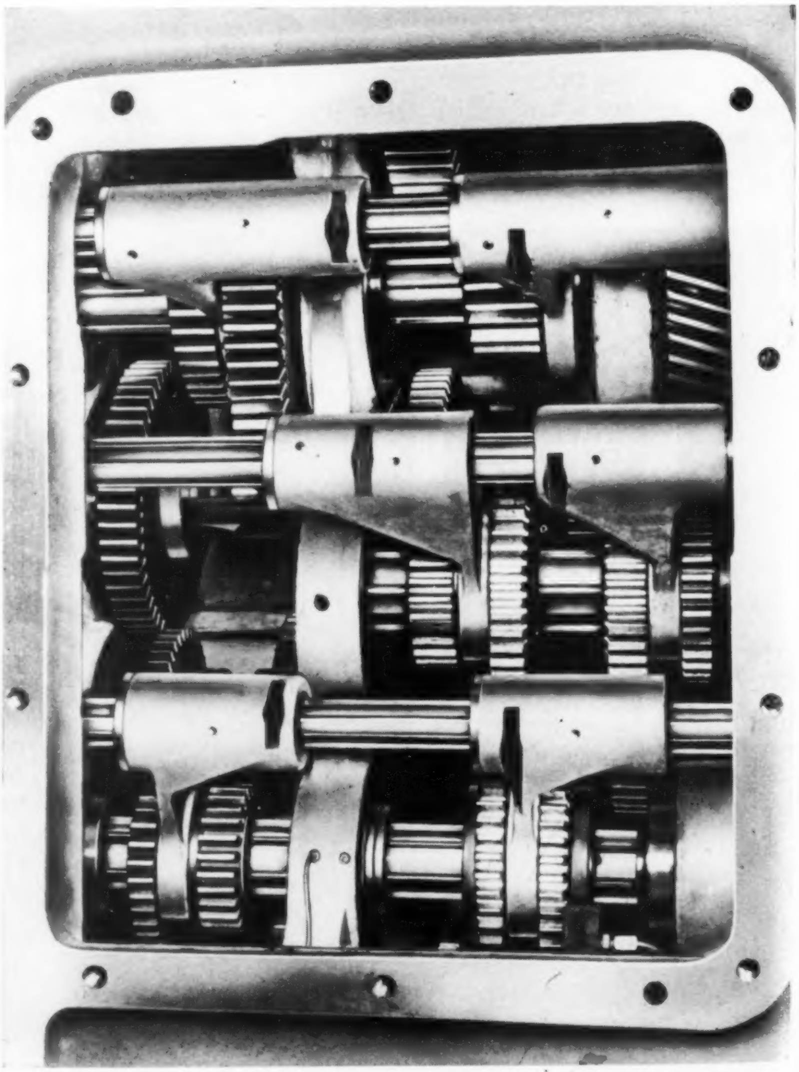
Preselection and Versatility



Feed preselector system uses cams on the selector shaft to actuate appropriate switches to actuate four of the eleven clutches in the feed drive gear for each speed. Diagram shows circuitry to engage one of these clutches. The cam shown is cut to complete one connection or the other of a single-pole, double-throw switch, or to make no connection depending upon speed setting of the selector dial. Two clutches are thus controlled. Assuming that the cam in the diagram has operated the switch to complete the circuit through contact 1 the operation is as follows: As the feed-change push button is pressed, relay 77 is energized. This opens contacts of all eleven clutch relays. When the button is released, relay 80 is energized and held by the holding contact shown in parallel with the switch. Other contacts open the line of relay 81 and any other clutch relay lines which should be kept off while this relay is on. Other clutches to be actuated for the desired feed combinations are selected and switched in a similar manner. Clutches are actuated by a separate 24 volt dc supply.

Optical indication of selected milling spindle direction, selected milling spindle speed (not preselected speed), preselected main feed direction, selected feed rate (not preselected feed) and the knee position with regard to the fall and rise device is provided by an electro-optical indicator in the side of the column. Preselected main feed direction is indicated by a double arrow; when feed is engaged only half of the arrow remains illuminated showing the feed direction. Each optical indicator consists of a circular glass disk mounted on the shaft of a servo receiver motor. In the case of the feed indicator fifty feeds are engraved near the edge of the disk. An optical projection system projects the selected feed onto a screen of glass rods or beads. Servo transmitter is connected to the selector shaft. A kilowatt meter next to the optical indicator shows power consumption of the machine.





Gear box for the milling spindle has hardened and ground gears on multispline shafts. Shifting of the sliding gears is electrohydraulic, solenoid valves and hydraulic cylinders being used to perform the shift. Selection of the required gearing is performed by turning one of two large concentric dials on the front of the machine to a position corresponding to the desired speed while the machine is cutting at some other speed. The change is not actually made until the operator pushes a button on the control panel. At this time the shift is performed automatically. A zero speed switch assures that actual shift of the sliding gears will occur only when the spindle is stationary. To assure smooth meshing, a small auxiliary motor rotates the gears during the shift.

GEAR-TOOTH BELT DRIVES

By Herbert Chase
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. . . applied for positive action on fixed centers

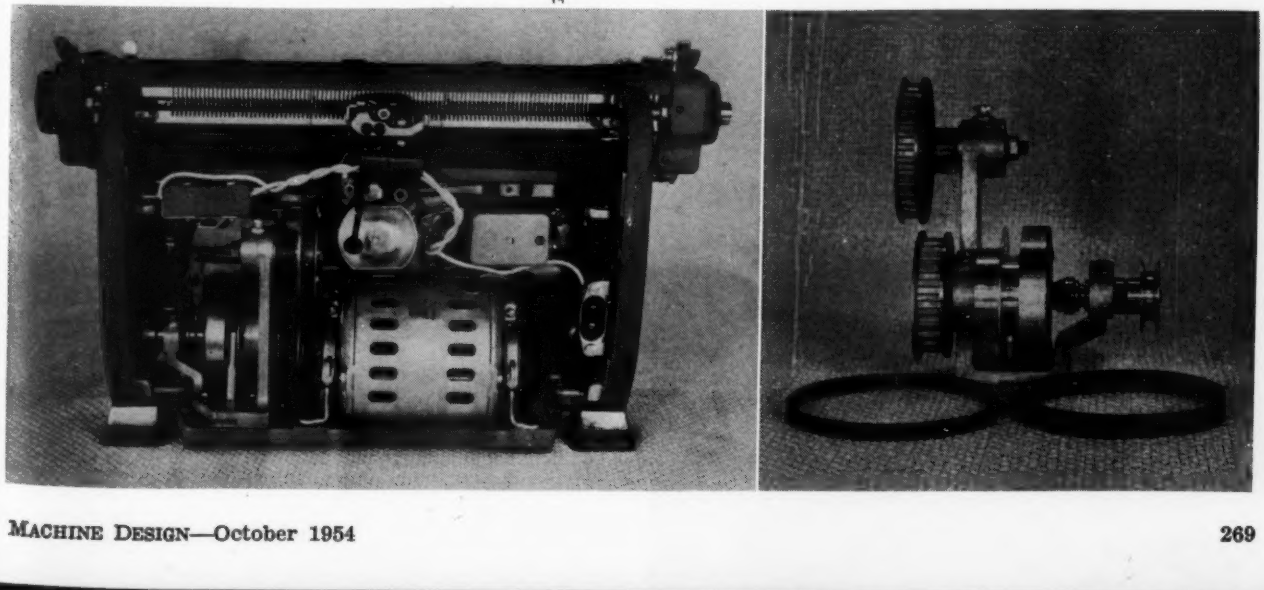
INTERMEDIATE between conventional belts and chains, and possessing advantages of both, is the flexible, toothed "Timing" belt. This type of belt provides a positive drive since its teeth mesh with those of the pulleys, which are really a form of sprocket or gear. Thus, slip is virtually nonexistent.

Drives using toothed belts offer several interesting possibilities. For example, especially in light drives, die-cast zinc-alloy pulleys are often used. Cost is low because teeth formed by the die require almost no machining save flash removal. Metal in these pulleys is not hard, but is usually adequate for good pulley life on average light drives. Pulley wear tends to be minimized by multiple tooth engagement, which keeps unit tooth loading low.

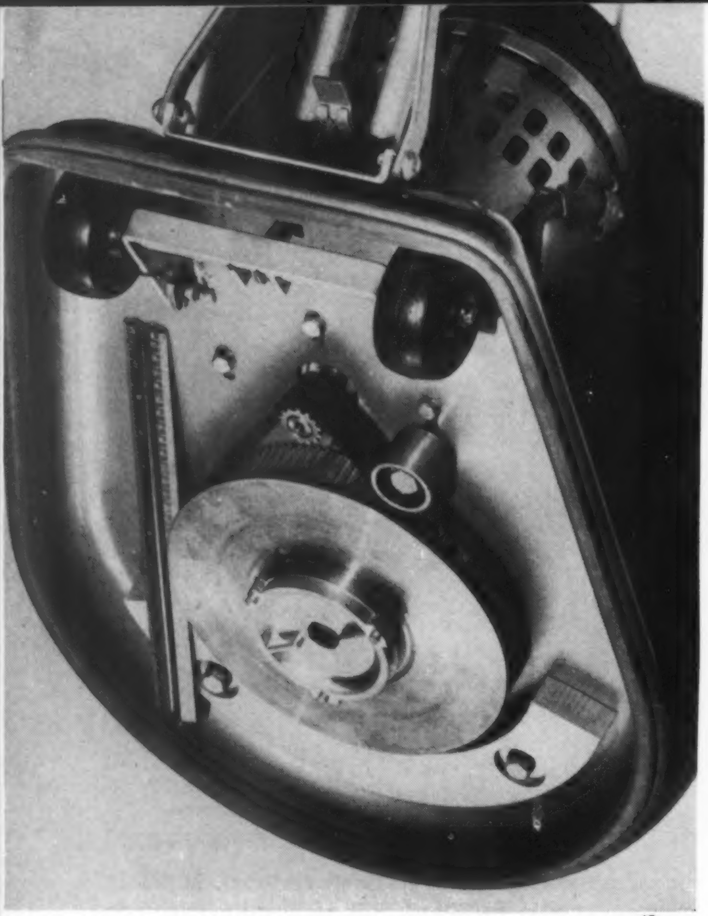
Machined pulleys made from steel, cast iron or nonferrous metals are widely used, but blanks must be machined and teeth cut in the same way as for conventional gears, and with similar charges for machining.

Some small pulleys have been made successfully from powdered metal, but dies for such pulleys commonly cost more than casting dies. Extruded pulleys with teeth are also feasible, but again require special equipment for manufacture. Application of separate flanges often is needed.

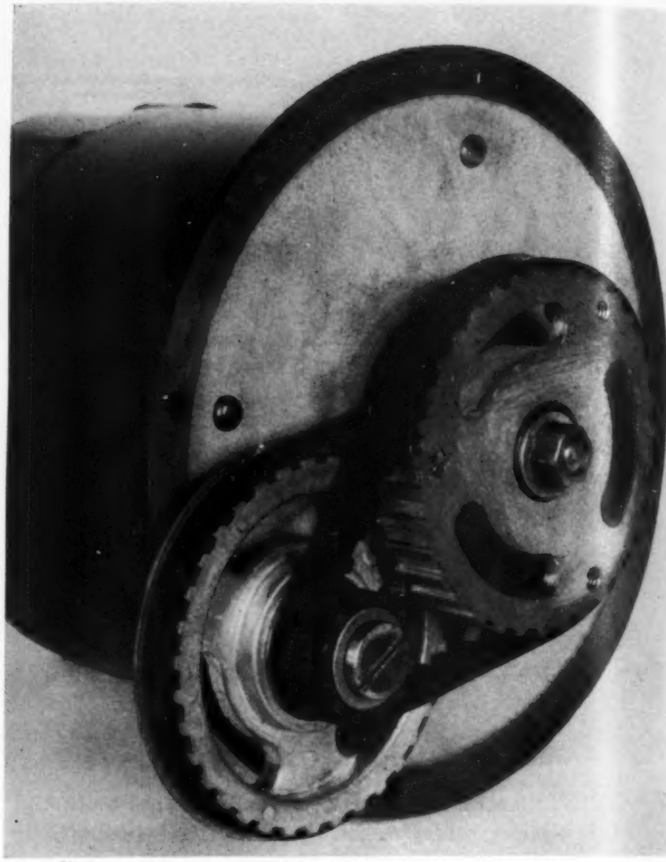
"Timing" belts, produced by the New York Belting and Packing Co. and the Mechanical Goods Div. of United States Rubber Co., consist of an oil-resistant synthetic rubber (neoprene) band



Double-reduction "timing" belt drive as applied to the Royal electric typewriter. Not shown is the driving pulley which is mounted on the motor shaft. All pulleys are die cast in zinc alloy and three of the four have double flanges

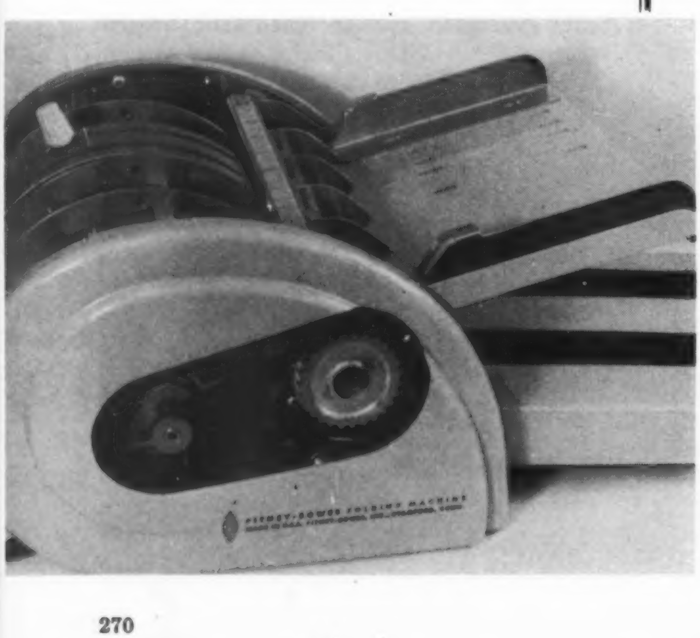


Under side of a Finnel floor maintenance machine. The toothed belt operates on very close centers and affords a large single reduction without slippage. Centers are fixed but a smooth idler runs on the outside of the belt



Double-reduction drive for a Hild floor polishing machine. Both large pulleys are zinc die castings, but smaller pulleys are of sintered iron, chosen because tooth pressures are high and harder surfaces than for zinc alloy are desired

A "timing" belt drive works well on this Pitney-Bowes folding machine. Low cost, comparatively quiet operation, fixed centers without slippage and absence of need for lubrication of the drive, with consequent cleanliness, are among the advantages



in which helically-wound steel wire cable is embedded. Integrally bonded to the wire-neoprene band are neoprene teeth protected by a facing of wear-resistant nylon fabric. Cable is used to provide high strength and to avoid stretch.

Because of freedom from stretch, the belt can be used on pulleys having fixed centers, and it is not necessary to provide idlers or other means of takeup, or to preload the belt. A smooth idler or a smooth power takeoff can be used, however, as on ordinary flat belt drives. The belt runs relatively quietly, even at high speed. At low speed, tests indicate that noise level is even lower than for cut gears running in oil.

With the Timing belt, oil or other lubricant is not required; oil-tight enclosures and lubrication devices are unnecessary. Most applications are relatively open and many, as in business machines for example, are used for this very reason, since frequent servicing is avoided and cleanliness improved.

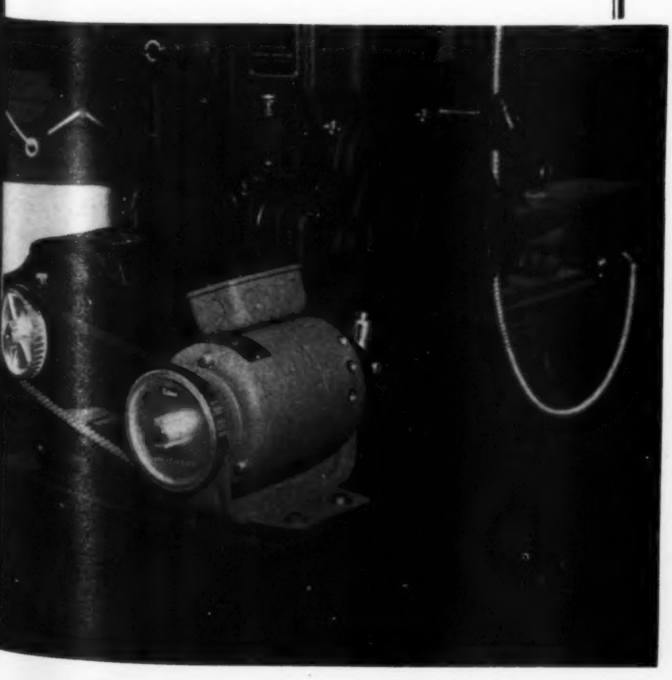
Because the toothed belt is relatively light, high belt speeds—even exceeding 15,000 fpm—are per-

missible, and the belt can be used with pulley diameters down to ½-inch. Since the belts are relatively thin and can be used on short centers, drives can be unusually compact. Drives involving the belts are said to be highly efficient, with values often exceeding 98 per cent.

Installation is similar to a V-belt drive. In general, pulleys should have flanges at both sides although, especially on close-center drives, one pulley having a single flange and occasionally one with no flanges can be used. In a die-cast pulley, one integral flange is an advantage from a production standpoint because flash then comes on a circle where it is easily removed rather than on tooth ends where removal is more difficult. Integral flanges strengthen teeth on any pulley but on those having cut teeth, which usually involve strong wrought metal anyway, a separate flange that facilitates cutting is preferred. On pulleys having double flanges, one flange must always be a separate piece, of course, to permit forming the teeth.

Teeth on pulleys do not have a true involute gear tooth shape but are designed to suit the shape of belt teeth. Some wear may occur on pulley teeth, especially if high belt pull produces high unit pressure on tooth surfaces. In die-cast zinc-alloy pulleys, which are not hard, wear may be more rapid than on harder metal, but rate of wear is very low and not usually sufficient to require pulley replacement during normal machine life. Teeth on zinc-alloy pulleys can easily be plated with hard chromium for wear resistance, and this has been done on a few applications involving high tooth pressures.

Three-dimension projector conversion unit driven from the motor's double-flanged die-cast pulley. Only one flange is required on the driven pulley even though the center distance is fairly long



Use of die-cast zinc-alloy pulleys has been accented here because these pulleys are lowest in cost, especially when production in relatively large quantities is required. In one application, two small (½-inch diameter) pulleys made from powdered iron are applied because the tooth pressure is quite high, and it was thought that the hardness of a sintered iron would be advantageous under these conditions. Stock pulleys are available, and some of these are adaptable to different shaft diameters by the use of tapered split hubs, making reboring to obtain a given shaft size unnecessary.

In conventional flat belt applications that involve a drive from a small to a relatively large pulley, slippage often exists at the small pulley. This slippage can be overcome by applying a toothed belt and a small toothed pulley (giving a positive drive at the small pulley end) without the expense of replacing the large pulley since the toothed belt will run on the smooth diameter of the larger pulley. In this case, however, initial tension is required as with a flat belt, and some slippage may occur over the large pulley since it has no teeth.

In this Tokheim gasoline dispensing unit, the pump is positively driven from the motor by a "timing" belt on fixed centers. Both pulleys are zinc die castings, both having a single integral flange. A second flange is added to the larger pulley

Designing for
Vibration and Shock Resistance

APPROXIMATELY 90 per cent of the damage to equipment resulting from shock and vibration can be eliminated in future designs using currently available components, provided those components are chosen, modified if necessary in view of past test experiences, and mounted on structures that have good damage resistance.

That is the major conclusion reached by engineers at the Naval Research Laboratory after an eight-year shock and vibration study of shipboard units, both electronic and nonelectronic. An analysis was made of 270 individual items, tested by NRL's Shock and Vibration Branch in accordance with prevailing Navy and military specifications. Equipment tested ranged in weight from 3025 pounds to less than 1 ounce and in size from a radar antenna measuring 17 feet across the tips of the reflector to small 30-ampere ferrule type fuse clips. Shipboard units were selected for study, since the extremely severe operating conditions on Naval vessels demand higher degrees of reliability and ruggedness than other military applications.

Contrary to previous belief, it was found that vibration was as damaging to the equipment tested as was shock, even though the inertia forces acting on the units during vibration were low compared with shock, normally between 2 to 5 g as compared to 300. Reason was the repetitive nature of vibration forces as compared with short-duration shock blows. Equipment well designed for vibration was usually resistant to shock, but equipment that passed shock tests might or might not have passed vibration tests. In the laboratory's investigations, vibration tests were performed first, except in the case of lighting units.

Test Results: Chassis, cabinets, and frame structures were found to be the principal areas of design which require more consideration by the designer. Most difficulties resulted from a lack of sufficient structural stiffness. Poor structural design not only caused damage to itself but was reflected in component performance under both vibration and shock and was perhaps the chief reason why components failed.

Tests showed that critical components should—and can—be arranged to benefit from the maximum deflections of the structure occurring during shock with very little increase in the damaging effect of vibration. One electronic unit tested, *Fig.* 1, was found to be damage-resistant even though not shock-mounted. Transformers are mounted low to lower the center of gravity. Aluminum mounting feet set in from the bottom edges permit greater deflection of the bottom panel under shock. Fortunately, the only components currently used which can be listed as critical are electron tubes and relays. Completely enclosed rotary-type relays and ruggedized electron tubes are possible—and promising—solutions to this problem.

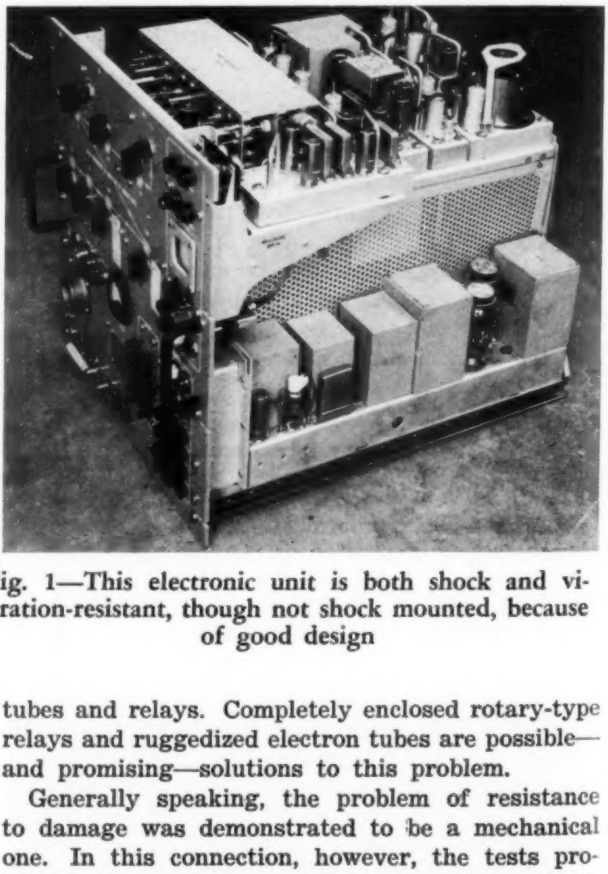
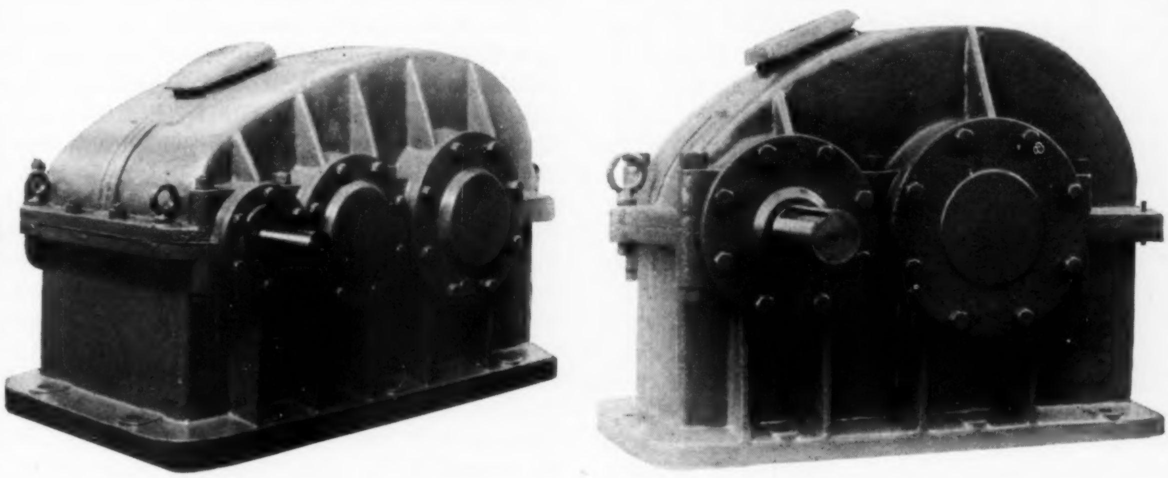


Fig. 1—This electronic unit is both shock and vibration-resistant, though not shock mounted, because of good design

Generally speaking, the problem of resistance to damage was demonstrated to be a mechanical one. In this connection, however, the tests provided strong evidence that just putting shock mounts on equipment is not enough to solve the shock and vibration problem. For example, in the case of lightweight equipment (electronic as well as nonelectronic), NRL investigators found that much equipment could pass the required tests without shock mounts. Apparently this was due to the fact that designers paid more attention to structural detail and component installation in this equipment. Admittedly, there are cases in which shock mounts should be used; an example is medium-weight, packaged electronic equipment, which usually requires shock mounts for the entire system.

Abstracted from "Designing for Vibration Resistance," *Research Reviews*, Office of Naval Research, March, 1954.

Fig. 22—Typical spur-gear reducers showing single and tandem double-reduction units. Gear combinations in these units can be varied but mating pairs must conform to center distance fixed by housing design. Photos, courtesy P. Merlini and Hijos S.R.L., Buenos Aires



Planning Machine Series—4

By Paolo Tedeschi
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Continuing the analysis of specific design problems begun in the preceding part, this article treats the significant concepts for systematic planning of gear reducer series. In the next and final article, several special techniques for series development will be considered

ALTHOUGH of primary importance in the planning of lines of turbomachines, the three criteria of efficiency, production cost and sales price take on a different aspect in the case of gear reducer series. Efficiency, in particular, is a factor of no value as a basis for analysis, since variations with load are essentially negligible. Other criteria which have more direct economic and commercial significance in series development must be considered.

On the basis of extent of commercial use, the fundamental types of gear reducers which are of greatest interest are: Spur, including helical and double-helical or herringbone; bevel, including straight-inclined bevel and spiral bevel; and worm. In this article, attention will be directed at the first of these categories, with emphasis on herringbone gear reducers. The same basic concepts, however, are also applicable to the other types and may be equally useful for series development, following procedures similar to those which will be discussed.

Within each fundamental type, selection of individual gear reducer units must be on the basis of increasing size. Size can be referred to the reducer housing only since each housing of specific dimensions permits the use of different gear combinations of varying transmission ratios, limited only by the condition that the center distance, C, between mating gears remains constant, *Figs.* 22 and 23. Thus the center distance is, in the majority of cases, the gear reducer geometrical module.

For bevel gear reducers, *Fig.* 24, the geometrical module is given by the pitch diameter of the driven gear. In this case, too, each housing may be designed to contain several sets of gears of different transmission ratios, *Fig.* 24.

Each gear reducer with a housing of specific size, having gears of a certain material and heat treatment made under a particular production method, may thus be readily adapted to different transmission ratios and, for each ratio, may be operated under varying rotational speeds. Since transmission capacity is a function of all of these variables, it follows that if the first two—housing size and gear quality—are fixed, the power quantity which defines the capacity of the housing, and represents its specific rating or operational module, can be established in terms of the other two variables, transmission ratio and speed. In each case, as will be seen, this quantity can be reduced from a double infinity of values to a single characteristic number if reference values are assigned to both variables and a law is established relating capacity to the value it will acquire under the reference conditions.

Similarity Criteria: According to present practice in gear calculations, gear resistance to wear, which is the fundamental basis of gear transmission capacity, is a function of general gear dimensions (pitch diameter, face width, tooth curvature) and the hardness and modulus of elasticity of the gear material. Tooth form, thickness, radial height and ultimate or endurance strength, depending on the material and the application, are only considered in checking the value of maximum allowable tangential load, which provides a measure of the danger of flexural failure of the gear teeth.

The Buckingham formula for wear resistance is well recognized as being one of the most useful calculation methods from the standpoint of suitability to a variety of gear applications and material characteristics. Further evidence of this general usefulness is given by the fact that this formula is being successfully applied not only to old and well-known materials but also to new ones, such as spheroidal (ductile) iron, which has a combination of physical characteristics entirely different from that associated with the "classic" materials.

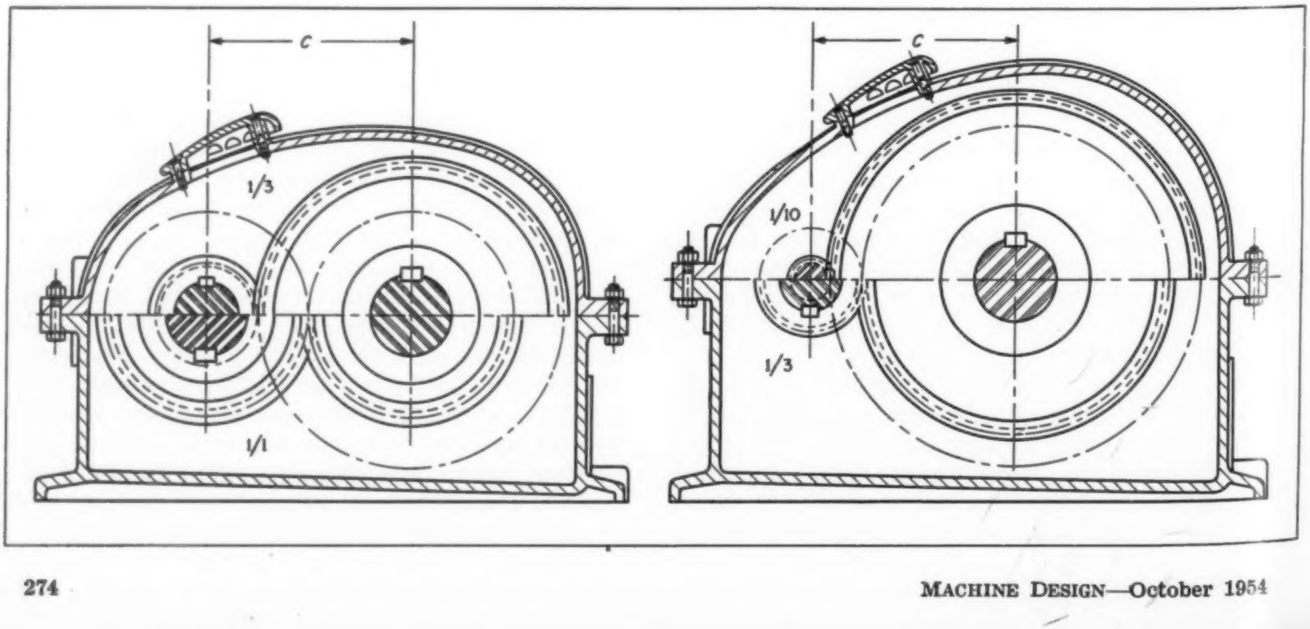
For the purposes of this analysis, it will be necessary to simplify the Buckingham formula by substituting for the effect of dynamic load a factor of reduction for the allowable load that is dependent on pitchline velocity. While this substitution is necessary here for reaching a clear synthesis of certain quantities, it is often performed in calculations based on unknown or unpredictable operating conditions, such as those existing in the case of any general-purpose commercial gear reducer.

The most common form of the simplified Buckingham formula is:

$$P = K\, k_z\, k_v\, D_P\, F v_m \qquad (53)$$

where P is the power capacity of the gears; D_P is the pitch diameter of the pinion; F is the effective face width; v_m is the pitch-line velocity; k_z is a factor based on the transmission ratio; k_v is the factor, accounting for the effect of additional dynamic load, which decreases as speed increases; and K is a coefficient which remains constant for a series of homologous gears. This coefficient K represents (1) all the constants making the formula homogeneous and (2) the re-

Fig. 23—Two single-reduction spur-gear reducers showing how different sets of mating gears with constant center distance can be mounted in standard housings. Use of two standard housings instead of one to provide range of transmission ratios from 1/1 to 1/10, in steps of 1/1 to 1/3 and 1/3 to 1/10, offers advantages in cost and size reduction



sistance to wear which is dependent on the elastic and hardness properties of the material and on that part of the tooth form having a direct influence on the compression stress.

In studying a series of geometrically similar gear reducers, if center distance C is taken as the principal geometrical dimension to which D_P, F and v_m are proportional and, for a first approach, k_z and k_v are assumed to be constant along the series, it is evident from Equation 53 that power P would be proportional to the cube of C.

The simplicity of this elementary law is, however, complicated by several circumstances, the most important being the decrease in the value of the velocity factor k_v, while D_P and consequently, v_m, increase. It is therefore probable that in an empirical formula directly relating P and C, the exponent of C will have a value less than 3. Moreover, such a formula will contain a factor, based on the transmission ratio, which not only replaces the factor, k_z, but serves primarily to account for the influence of the transmission ratio on D_P and v_m.

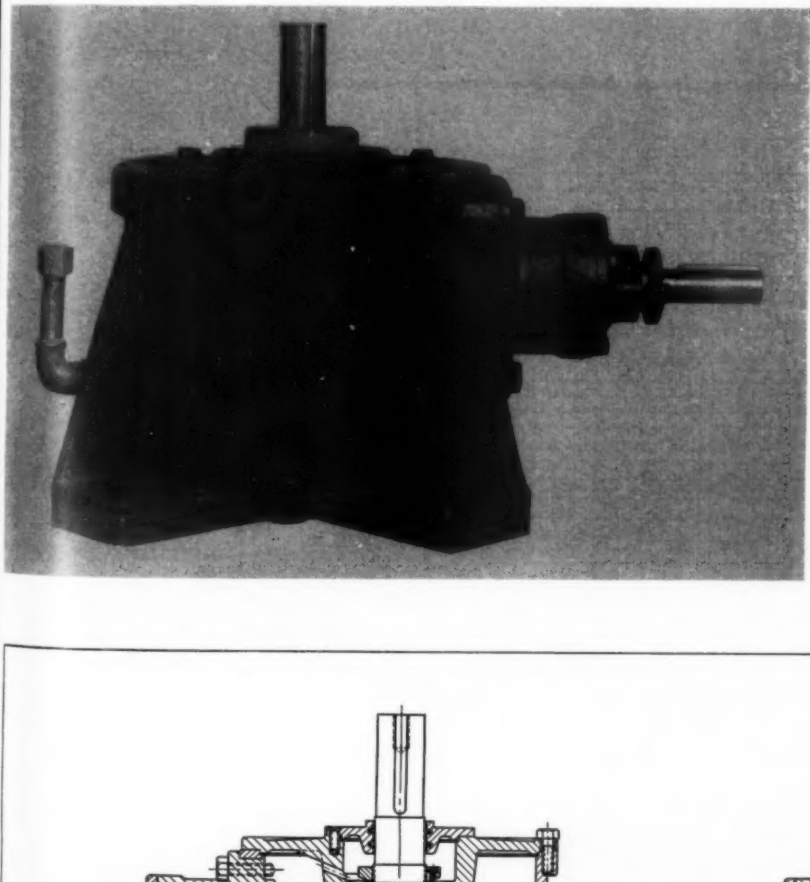
PLANNING MACHINE SERIES

Laws of Similarity: From a careful analysis of several series of gear reducers, based on the concepts previously discussed, it has been found that center distances and capacities may be interrelated by simple expressions. These relationships may perhaps be best defined as tentative similarity laws for gear reducers.

Let P be the transmission capacity in horse power, of a gear reducer under the conditions defined by American Gear Manufacturers Association Standards* for a service factor of 1.00; C be the center distance in inches; f_m be a factor based on transmission ratio; f_p be a factor based on pinion velocity; and δ be a factor based on fundamental design criteria. Then, from the results of the general analysis just described,

$$P = f_m f_p \delta C^{2.75} \quad (54)$$

* *AGMA Standard Practice, Helical and Herringbone Gear Speed Reducers*—Gears 420.02 (February 1951).



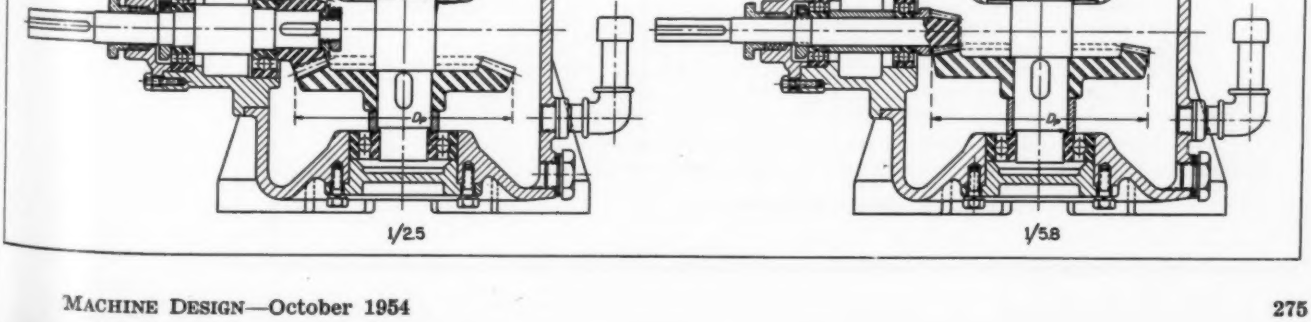


Fig. 24—Typical bevel-gear reducer units for cooling-tower fan applications. Cross-section views illustrate how same standard housing can be utilized for different gear sets. Photo, courtesy P. Merlini and Hijos, S.R.L., Buenos Aires

As will be shown, factor $f_m = 1$ when the transmission ratio $m = 1$, and $f_p = 1$ when the pinion speed $n_P = 100$ rpm. Under these reference conditions, Equation 54 becomes,

$$P_0 = \delta C^{2.75} \quad (55)$$

where P_0 represents the particular value of P corresponding the reference conditions. Thus, if the values $m = 1$ and $n_P = 100$ rpm are established by convention as the standard reference conditions, P_0 may be defined as the reference power or *specific rating* of the gear reducer.

For the most common type of steel herringbone gears in general use today—300 bhn, 30-degree helix angle, 20-degree pressure angle— the factor δ has the following values:

Gear Reduction	Low Value	Average Value	High Value
Single	0.080	0.100	0.115
Double (tandem)	0.006	0.007	0.008
Triple (tandem)	0.0006	0.0007	0.0008

Selection of a low, average or high value of δ is dependent on certain basic design considerations; principally, the relative face width of the gears or, in reference to the housing, whether the shape is narrow and long or broad and short. In general, δ will remain constant over a broad central zone of a line of reducers; however, for the small size units, higher values of δ are permissible and for the large units lower values must be adopted.

Values of the factor f_m can be determined from the following empirical equations: For simple gear reducers (single reduction) with transmission ratios, m, ranging from 2 to 10,

$$f_m = \frac{1.004}{m} - 0.004m \quad (56)$$

for double-reduction units with m ranging from 10 to 80,

$$f_m = \frac{1.004}{\sqrt{m}} - 0.004\sqrt{m} \quad (57)$$

and for triple-reduction units with m ranging from 80 to 600,

$$f_m = \frac{1.004}{\sqrt[3]{m}} - 0.004\sqrt[3]{m} \quad (58)$$

For convenience in analysis, curve plots of these

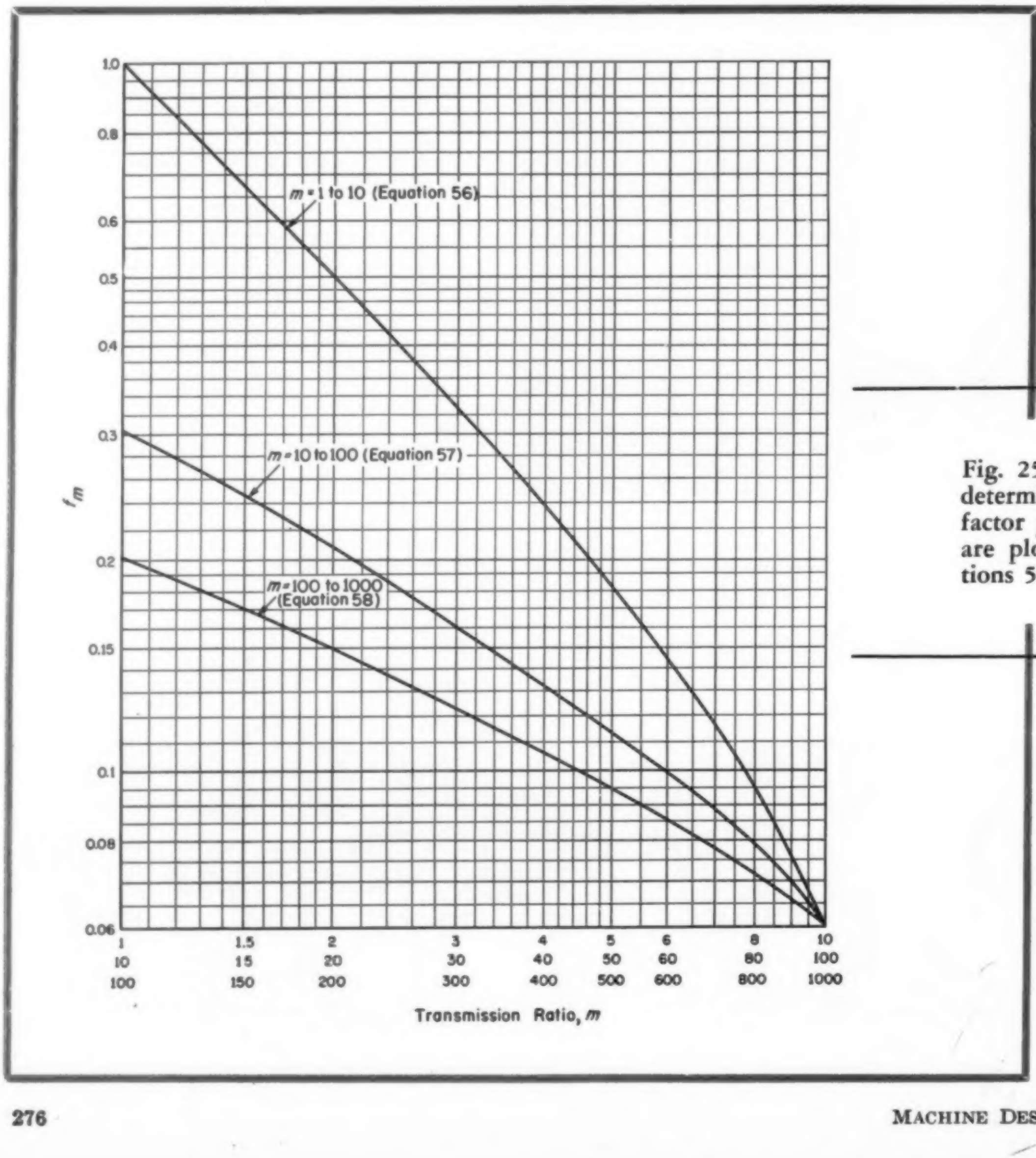


Fig. 25—Chart for determination of factor f_m. Curves are plots of Equations 56, 57 and 58

three equations are given in *Fig.* 25.

Values of the factor f_p for single, double and triple-reduction units operating at pinion speeds, n_p, ranging from 500 to 2000 rpm are given by

$$f_p = \left(\frac{n_p}{100} \right)^{0.875} \quad \text{(59)}$$

This equation has been plotted in curve form in *Fig.* 26.

On first inspection, it might seem that the reference conditions for specific rating, $m = 1$ and $n_p = 100$ rpm, are not in accord with actual practice. However, it will be found that the requirement of $f_m f_p = 1$, for which $P = P_0$, is fulfilled not only for the reference conditions but also for other combinations of m and n_p falling within the normal range of gear applications. For example, in the case of the usual standard 60-cycle motor speeds, the values of n_p and m for which $f_m f_p = 1$ are:

	m		
n_p (rpm)	**Single Reduction**	**Double Reduction**	**Triple Reduction**
580	4.36	19	83
870	5.75	33	190
1160	6.95	48.3	335
1740	8.65	75	645

The specific rating of a gear reducer of given capacity P, pinion speed n_p and transmission ratio m is given by

$$P_0 = \frac{P}{f_m f_p} \quad \text{(60)}$$

where f_m and f_p have values corresponding to reducer transmission ratio and pinion speed, respectively.

From Equations 54 and 55, expressions can now be developed for the required center distance of a gear reducer. These expressions are:

$$C = \left(\frac{P}{\delta f_m f_p} \right)^{1/2.75} \quad \text{(61)}$$

$$C = \left(\frac{P_0}{\delta} \right)^{1/2.75} \quad \text{(62)}$$

To simplify calculations involving quantities raised to the 2.75 or 1/2.75 power, the graphical conversion scale in the form of a contact-scale nomogram given in *Fig.* 27 may be helpful.

Module Relationships: For gear reducers, geometrical modules are given by the center distances, C, and operational modules by the specific ratings, P_0. Equation 55 is therefore the fundamental law of a reducer line. Its function in the planning of a series is analogous to that of the similarity laws in the case of hydraulic turbomachines.

This equation, which provides a direct relationship between the two modules, offers another example of the practical application of the general expression given in Equation 1 (*Part* 1): $W = kL^{\epsilon}$. In Equation 55, $W = P_0$, $L = C$, $\epsilon = 2.75$ and $k = \delta$.

This homology of terms can be utilized as a

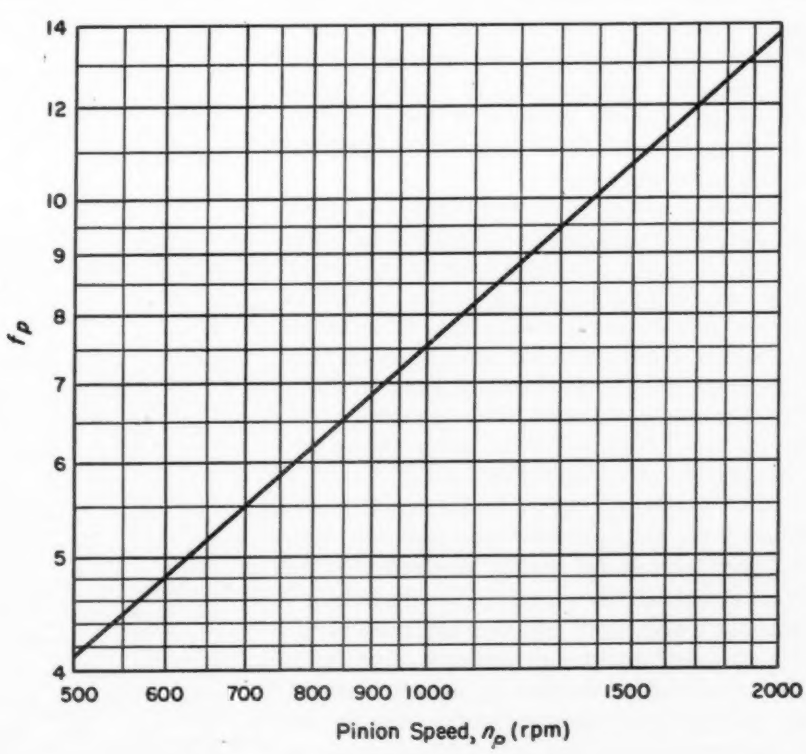


Fig. 26—Chart for determination of factor f_p. Curve is plot of Equation 59

basis to directly relate not only P with C but also the characteristics of a given series of operational modules (specific ratings or effective powers) with those of a corresponding series of geometrical modules (center distances). Thus, from the basic properties of conventional and second-order progressions discussed in *Part* 2, it is evident that if the ratio between limiting terms of a given series of operational modules is R, the analogous ratio for the corresponding series of geometrical modules is $R^{1/2.75}$. If these series are based on second-order progressions, the second-order ratios, ρ, also could be established in a similar manner.

Series Planning Concepts: In establishing the limiting terms of a series of specific ratings, the determining criterion is the feasibility of extending the line to include power ratings of lesser sale value. These limits must be fixed by a careful investigation of the market, performed in an alert commercial spirit and with even some prophetic interpretations. As a matter of fact, those companies for which a low upper limit seems to be at present adequate are logically those where an extension would probably be more desirable in the future. In such instances, the series may be limited initially but must be planned so as to make future extension of the line fairly simple. Another possibility is to plan an extensive line initially for gradual application as requirements develop.

Term ratios in a gear-reducer series must decrease in going from low to high specific ratings, indicating the application of a second-order progression for tracing the development of the line. In selecting a progression, care must be exercised to assure that ratios between subsequent terms, or specific rating values, maintain certain inverse proportions among the ratings in accordance with the criteria previously discussed, as well as other considerations which will be demonstrated in dealing with practical applications of these general concepts. Moreover, the number of terms in the series must fall within the range for minimum total cost established in *Part* 1.

With reference to the geometrical modules (center distance), it is evident that the limiting units of the module series must be carefully checked against available production methods. It would hardly be of much use to plan a line of reducers which involves gears of a larger diameter than can be handled by the available milling machine capacity, or pinions so small that the production methods in use would result in form errors too large for the speed of operation, etc.

When the series of operational modules has been determined, the corresponding series of geometrical modules can be readily derived through the use of Equation 62, adopting for the factor δ the particular value that fits the application. To provide a complete picture at the first, this series derivation could be performed by merely converting the progression characteristics (limits and ratios), using the equations and methods given in *Part* 2. For the final development, calculation

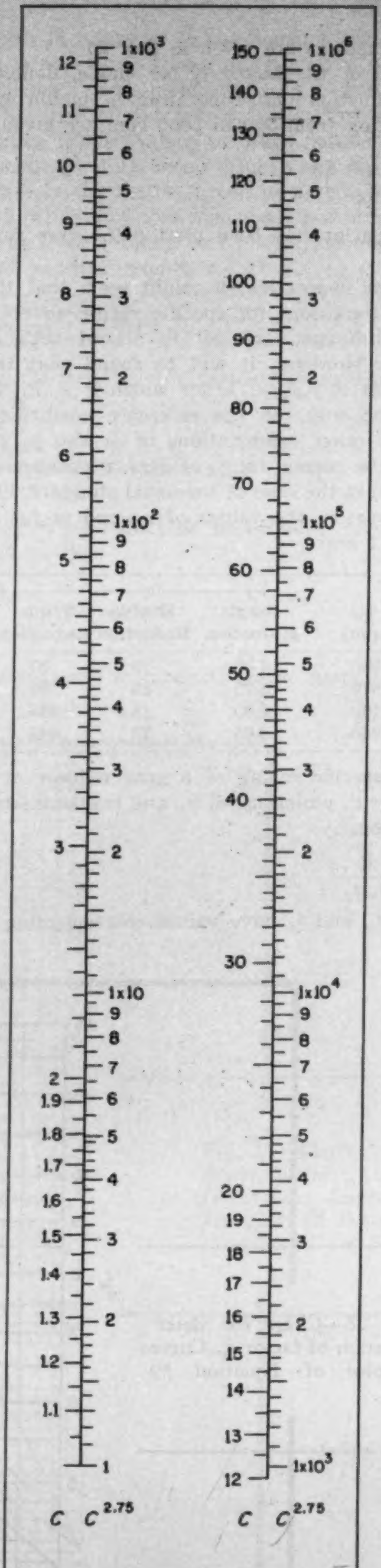


Fig. 27 — Conversion scale for calculations involving numerical quantities raised to the 2.75 or 1/2.75 power

of the derived series term by term will probably be necessary.

Analyzing Existing Series: Gear reducer lines with irregular variations in the ratios between subsequent power ratings are often found. If these series are analyzed by the methods which have been discussed, the irrational features can be readily found and traced to their origin.

To perform such an analysis it will be necessary to first (1) reduce the available data on capacity into terms of specific ratings by means of Equation 60 and (2) calculate for every reducer of the line the value of the factor δ from Equation 55.

In an ideal case, δ would remain constant along the entire line. A slow and continuous increasing or decreasing value of δ is not a sign of irrationality. This uniform variation only indicates that for the particular series the exponent of C is slightly different from the mean value of 2.75 which has been derived from empirical-statistical investigation and to a point, depends on design criteria.

A clear sign of a defect in the particular line, on the other hand, is indicated by an irregular variation of δ. This discontinuity reveals that some of the housings, particularly those to which the lower values of δ correspond, could have been better utilized by employing gears of higher capacity. In such instances, an irregular variation in the ratios of subsequent power ratings is also usually present. This fault indicates that a series could be found which falls within the same limiting ratings and has the same maximum ratios but a smaller number of models, or that a line could be developed, with the same number of models but at lower ratios, which would have better commercial characteristics.

An examination of these defective lines quickly exposes the origin of such irregularities. In general, the causes are: (1) The lines are based not on a pre-established series of power ratings but on a series of center distances and (2) these series are formed on the basis of subsequent arithmetic

progressions of integers. This inversion of procedure together with a preference for integers and arithmetical progressions are jointly capable of producing a series which is far from rational, even in the cases where, during the tabulation of power ratings, the most evident and prominent discrepancies are smoothed out, as often occurs.

Practical Example of Series Planning: Application of the preceding concepts in actual practice is demonstrated by the following example in which the development of a complete line of simple, tandem-double and tandem-triple gear reducers, with gears of a standard type, is described. For this particular line, the gear reducers are assumed to be of the general-purpose type and have steel herringbone gears, cut to form after the material has been heat treated to about 300 bhn.

Basic data for the complete line have been collected in the top section of *Table* 12. These data represent the hypothetical results of a previous commercial market research.

Approximate maximum allowable ratios for the progression of specific ratings, determined in accordance with concepts previously considered and representing the designers commercial sensibility in the present case, have been established as follows: For ratings around 10 hp, a value of 2; around 100 hp, a value of 1.5; around 1000 hp, a value of 1.25; and around 2500 hp, 1.10.

From a survey of available tooling, it has been found that gear sizes are governed by the following production limitations: Finest diametral pitch, 24; minimum number of teeth, 12; minimum pitch diameter (25-degree helix angle), 0.552 inch; maximum pitch diameter, 84 inches.

Values of δ given in the basic data in *Table* 12 correspond to the average values of "face to diam-

Table 12—Planning Data for Line of Gear Reducers

Item	Single-Reduction	Double-Reduction	Triple-Reduction
Basic Data:			
Specific rating, P_0 (hp)	4-2500	4-500	4-250
Transmission ratio, m	1.25-10	9-81	80-400
Design factor, δ	0.10	0.007	0.0007
First Approach:			
Center distance, C (in.)	3.8-39.7	10.1-58.2	23.2-104.5
Smallest pinion, D_P (in.)	0.691	0.808	1.167
Largest gear, D_G (in.)	72.2	62.9	87.4
Second Approach:			
Specific rating, P_0 (hp)	4-2500	4-700	4-170
Design factor, δ	0.11-0.07	0.008-0.005	0.0008-0.0006
Center distance, C (in.)	3.7-45.2	9.6-74.4	22.1-96.1
Smallest pinion, D_P (in.)	0.673	0.768	1.109
Largest gear, D_G (in.)	82.2	80.3	80.4

eter" ratio. For a first approach these values are assumed to be constant along the entire series. In the subsequent phases of calculation, these values will be corrected to agree with the actual center distances employed; for the small models the values will be increased and for the larger models they will be decreased.

In the first approach to series planning, the initial step is the calculation of the center distances corresponding to the desired specific ratings. Equation 62 is utilized for this calculation, taking appropriate values for the basic data in *Table* 12. Before continuing with complete development of the line, it will be necessary to verify, making adjustments if necessary, that these first rough calculated dimensions are in agreement with the limitations of available production equipment, especially in regard to gear diameters.

The pitch diameter D_P of the smallest pinion in the smallest gear reducer unit of a series may be determined from the equations:

For single reduction units,

$$D_P = \frac{2\,C}{m+1}$$

For double-reduction units,

$$D_P = \frac{0.8\,C}{\sqrt{m}+1}$$

For triple-reduction units,

$$D_P = \frac{0.42\,C}{\sqrt[3]{m}+1}$$

The pitch diameter D_G of the large gear of the largest unit may be likewise found from the equations:

For single-reduction units,

$$D_G = 2C\,\frac{m}{m+1}$$

For double-reduction units,

$$D_G = 1.2C\,\frac{\sqrt{m}}{\sqrt{m}+1}$$

For triple-reduction units,

$$D_G = 0.95C\,\frac{\sqrt[3]{m}}{\sqrt[3]{m}+1}$$

The foregoing equations are based on the following assumptions: (1) Intermediate gear ratios in multiple reduction units are equal and (2) intermediate center distances in the tandem double-reduction units are in the proportion 1/1.5, while for the tandem triple-reduction units the proportion is 1/1.5/2.25. These assumptions represent only average conditions; hence, the foregoing equations are only approximate expressions. For final calculations pitch diameters must be checked against the actual proportional relationships of intermediate gear ratios and center distances.

Table 13—Development of Line of Gear Reducers*

Progression Data			Specific Rating,	Single Reduction Units			Tandem-Double Reduction Units			Tandem-Triple Reduction Units		
Term Values 18-6-C‡	Term Values 56-15-B‡	Ratios	P_0 (hp)	Model No.	δ	C (in.)	Model No.	δ	C (in.)	Model No.	δ	C (in.)
1.000		....	4.0	S1	0.11	3.68	D1	0.008	9.55	T1	0.0008	22.1
1.995		1.995	7.9	S2	0.10	4.90	D2	0.007	12.9	T2	0.0007	29.8
3.758		1.884	14.9	S3	0.10	6.17	D3	0.007	16.2	T3	0.0007	37.5
6.683		1.778	26.5	S4	0.10	7.67	D4	0.007	20	T4	0.0007	46.2
11.22	1.000	1.679	44.5	S5	0.10	9.18	D5	0.007	22.5	T5	0.0007	55.8
17.78	1.584	1.584	71	S6	0.10	10.9	D6	0.007	28.5	T6	0.0007	65.9
	2.446	1.543	108	S7	0.10	12.7	D7	0.007	33.4	T7	0.00068	78.0
	3.676	1.503	163	S8	0.10	14.8	D8	0.0065	39.8	T8	0.00065	92.0
	5.380	1.464	239	S9	0.10	16.9	D9	0.006	47.1			
	7.666	1.425	340	S10	0.10	19.3	D10	0.0055	55.3			
	10.64	1.388	475	S11	0.10	21.7	D11	0.005	64.5			
	14.38	1.351	640	S12	0.10	24.2	D12	0.005	71.9			
	18.92	1.316	840	S13	0.095	27.2						
	24.24	1.281	1075	S14	0.092	30.2						
	30.25	1.248	1360	S15	0.090	33.0						
	36.75	1.215	1630	S16	0.085	36.1						
	43.49	1.183	1930	S17	0.080	39.3						
	50.11	1.152	2230	S18	0.075	43.3						
	56.23	1.122	2500	S19	0.070	45.2						

*Values have been rounded off from calculated figures. Thus, if a check calculation is made, it is possible that the values may not correspond exactly. ‡Progression taken from *Table* 5, *Part* 2.

Calculated data for the first approach are listed in the middle section of *Table* 12. Pinion and gear diameters have been determined from the previous equations. The smallest pinion pitch diameters are acceptable, since all are larger than the minimum diameter established by the limitations of the production equipment. However, comparison of the calculated largest gear diameters with available facilities indicates that some size modifications are necessary, not only because the calculated pitch diameter of the large gear of the triple-reduction units is larger than the allowable maximum but also because the large gear of the double-reduction units is smaller than the allowable maximum and permits extension of this portion of the line. Moreover, the center distances obtained through this first calculation go beyond the limits of a constant value of δ, necessitating correction of this factor in the second approach.

Corrected results for the second approach are listed at the bottom of *Table* 12. A more desirable balance between the large gear sizes has been attained and the gears are within the acceptable limits of the available production facilities. In addition, the maximum rating for double-reduction units can be extended from 500 to 700 hp, while for the triple-reduction units this rating must be reduced from 250 to 170 hp.

To complete the development of the line, a suitable progression of specific ratings must now be found. This progression must connect the limiting values of 4 and 2500 hp, providing limiting and intermediate ratios in close agreement with the values initially fixed in this example.

The ratio of limiting progression terms, 2500/4 = 625, does not correspond to any of the planned progressions listed in *Table* 5 of *Part* 2. In reaching the desired objective, it will be necessary to use a combination of two of the progressions, selected on the basis of the following criteria: (1) The last term ratio of the first progression must be equal to the first term ratio of the second progression and (2) the second order ratio, ρ, of the second series must be greater (closer to unity) than that of the first series. The reasons for the first condition are apparent. The latter requirement is imposed for convenience in "decelerating" the reduction of first-order term ratios in the final progression, leading to a result that may perhaps be best defined as an approximate third-order progression. Application of this type of progression, which was discussed in *Part* 2, becomes necessary when progressions with large ratios between limiting terms are involved.

Development of the complete line of gear reducers is shown in *Table* 13. This final grouping is based on a progression which combines two of the planned second-order progressions: 18-6-C and 56-15-B. Center distances C are determined through a trial and error procedure in which the values of δ are corrected to correspond to the values of C in a manner similar to that used in the second general approach.

As a final check, the number of terms in the series of center distances should be compared against the criteria presented in *Part* 1. The initial range with ratio of extreme terms equal to 10, going from 3.68 to 36.1 inches, is covered by 16 terms, a number which falls within the zone of maximum convenience, on the high side. The latter characteristic is justified by the nature of the line which is composed of gear reducers intended for general sales.

Final Design Consideration: The equations which have been developed in this article are merely for the purpose of guidance in rational series planning and are not in any way intended as substitutes for the Buckingham formulas or similar basic gear calculation methods. On the other hand, the actual design of the models of a series must be based on these equations exclusively in establishing a rational arrangement of the specific ratings and the corresponding center distance dimensions by which those ratings will thus be realized. For applications involving power ratings other than the specific ratings and conditions different from those discussed here, calculations will have to be accomplished by the conventional techniques in use.

During the final design stages, adherence to the pre-established ratings is readily achieved by specifying adequate face width and pitches. Necessary corrections should only be minor and within the range of possibility, since the methods which have been presented here are based on analyses of actual lines of gear reducers.

In calculating final dimensions, it should always be remembered that the primary objective is the attainment of economic and commercial rationality in the series of ratings and not necessarily regularity in the series of geometric dimensions.

In the next and concluding article of this five-part series, consideration will be given to several design problems involving special techniques of series planning. Characteristics and methods of attack for reciprocating machines, centrifugal governors, servomotor controllers and constant speed pumps will be treated.

They Say . . .

"Although it has been less than 12 years since the power of the atom was harnessed within a nuclear reactor, we have already made tremendous progress in research and development in connection with agriculture, chemistry, metallurgy, biology, medicine and other areas of science and industry. Additionally, we have seen significant advances in new fundamental knowledge, and I am confident that new discoveries will appear, fully as important as those we have already witnessed, and that they will further enrich the lives of all of us. We are not yet at high noon of the atomic age—only at the first glimmer of its dawning."—Lewis L. Strauss, *chairman, Atomic Energy Commission.*

Transistors

DESIGN ABSTRACTS

. . . offer a wide range of possibilities in machine control applications

By R. L. Bright
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SINCE their inception some six years ago, transistors have been the subject of considerable interest and development effort. Despite this activity, applications in commercial equipment have developed slowly. Early predictions of large scale replacement of vacuum tubes have not yet materialized and probably will not for many more years simply because the transistor is not a vacuum tube. Its usefulness stems from a unique combination of properties which can, and undoubtedly will, be adapted to advantage in a variety of control functions.

Transistors have some characteristics that are similar to those of vacuum tubes, but they also differ in many important respects. The grid of a vacuum tube draws practically no power from the signal source; a transistor, on the other hand, requires a small but often appreciable amount. In most applications, vacuum tube characteristics may be considered invarient with temperature; some of the transistor's properties vary greatly with temperature. It is therefore not surprising that transistors have had difficulty in replacing tubes in the circuits and applications that have evolved over the past thirty years. These circuits were tailored to take advantage of the vacuum tubes' unique properties, some of which transistors do not even possess.

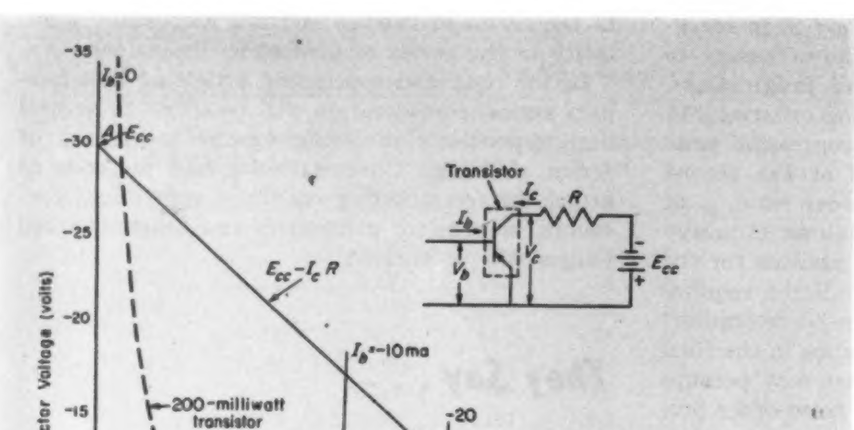

Fig. 1—Curve showing relationship in a 200 milliwatt transistor between voltage across the unit and fixed input load currents

Basic Characteristics: In attempting to apply transistors, it seems more reasonable to look carefully at the characteristics of the device to determine if it has any unique properties which will enable it to perform functions that are not practical with vacuum tubes. It has several such unique properties. The one of principal interest here is the ability of the transistor to control power flow with an overall efficiency of 98 or 99 per cent. The transistor has this property by virtue of a more basic property, namely the very small voltage drop across the unit under the proper conditions. This drop is less than 1 volt for quite large current densities. The efficiencies it permits can be matched only by high-voltage ignitrons. These efficiencies coupled with the transistor's great reliability portend a very extensive potential application of transistors in the power control field in the next two or

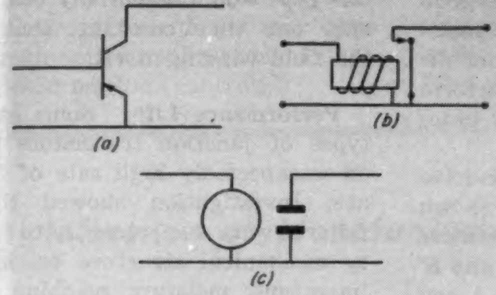

Fig. 2 — Equivalent circuit diagrams at *a* for a transistor used as a relay and at *b* and *c* for standard relays

three years.

This time estimate is not overoptimistic. Two years ago, the largest germanium rectifier, which is a relative of the transistor, had a current rating measured in milliamperes. Today, there are under development units with a rating which may be as high as 200 amperes average at 65 volts peak inverse, or 8 kilowatts apiece. There is good reason to expect that transistors capable of controlling kilowatts will likewise be available in another one or two years.

The unique characteristics and the proper operating conditions referred to earlier are illustrated in *Fig.* 1. This is a graph of the collector characteristics of a Westinghouse 2N55, PNP, fused junction transistor.

In its commercial form, it is a small plastic cylinder about 3/8 inches in diameter and 3/16 inches high and is, thus, about the size of the tip of a little finger. Its rated power dissipation at room temperature is 200 milliwatts—hardly a high power unit. Nevertheless, it will serve to illustrate the principles involved.

The graph in *Fig.* 1 shows the relationship between the voltage across the unit and the load current through it for fixed values of input current. If, for example, this transistor should be connected in series with a dc supply and a resistance load, the operating point of the transistor will be along the line shown. If the input were such that the operating point was near the center of this line, the power dissipation, which is the product of voltage across the unit and the current through it, is far above the maximum rated 200 milliwatts. However, if the operating point is near point *A*, the load current is so small that even though practically the entire supply voltage appears across the transistor, the power dissipation in the unit is still less than the rated value. Similarly, if the base drive is made sufficiently large, the operating point will move down to point *S*. Here, we have a large current through the unit but only a very small voltage across it; here again the power dissipation is less than the rated 200 milliwatt. However, the power in the load under this condition is approximately equal to the load current times the supply voltage, or about 4.2 watts. This transistor can actually control a load power equal to about 50 times the rated dissipation if its operating points are restricted to lie at the ends of the load line and if the switching time is very fast. The transistor when operated in this manner is analogous to a relay which closes a switch in series with the load when the input to its coil is energized, *Fig.* 2. This characteristic is, of course, of prime importance to the machine tool industry. The remainder of this discussion will be devoted to the possible applications of such "switching" transistors.

In the application of transistors, one of the major obstacles has been the difficulty of obtaining a stable operating point since the entire family of voltage versus current characteristics shown in *Fig.* 1 moves considerably with temperature and may differ significantly from unit to unit. Since "switching" characteristics apply only at the two extremes of the load line, these effects are of only secondary importance. Thus, it should be emphasized that transistors when used as switches are not subject to the severe temperature restriction which is generally accorded them and which apply to linear amplifiers. On the contrary, in many applications, such transistor circuits will meet most military specifications. Furthermore, the transistors do not need to be carefully selected. In switching service, all transistors of a given type will be completely interchangeable.

Control Applications: An obvious application of this device would be to replace a relay and take advantage of the fact that a transistor can operate at very high speeds and has no contacts to pit or get dirty. The transistor has the limitation that it is only a three terminal device and, hence, it must have one lead common to both input and output. Furthermore, it effectively carries only the one contact. Nevertheless, many power control circuits can probably be redesigned to incorporate such units.

Two such switching transistors can be used to make a variable-frequency power amplifier as shown in *Fig.* 3. If a square wave is applied to the input of this circuit, the two transistors are alternately turned on and off, thereby connecting the supply battery to alternate ends of the winding and, thus, producing a square wave at the output of the same frequency but of a much higher power than the input. One possible application of this device might be as a component in a tape-controlled machine tool. For example, speed information could be recorded on the tape as a square wave of variable frequency; the pickup head might feed into an all transistor

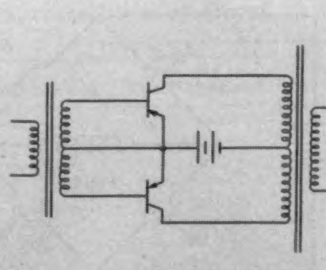

Fig. 3—Circuit diagram of two switching transistors used to make a variable-frequency power amplifier

amplifier having two or three stages of the type just shown. The output of this amplifier could drive a synchronous motor at the required speed. This system would provide a precise speed control without feedback loop complexity.

Thus far, the discussion has indicated how a transistor might be used to pass or block current from a dc supply. With minor circuit variations, transistors can also be used to pass alternating currents and block alternating voltages. Thus, it is quite conceivable that they may replace contactors in induction motor starters and other ac equipment.

The use of a transistor as a switch which is either on or off suggests a thyratron or ignitron which is also an on-off device. One difference is that the gas tube is fundamentally a high-voltage, low-current device whereas the transistor seems destined to be a low-voltage, high-current unit. However, a more important distinction is that the transistor possesses two great advantages over the thyratron which makes its application much more flexible: (1) It can carry or block currents in either direction and (2) it can be turned on or off at any desired instant. With proper driving circuitry, the transistor can be made to perform as a thyratron, but not conversely.

For example, a static field control circuit that may replace rotating amplifiers and exciters is shown in *Fig.* 4. Here, advantage is taken of the fact that the transistor can pass current in either direction and, hence, can perform functions which are not now practical with thyratrons.

In this circuit, the base-drive circuits which have not been shown in detail are such that transistors *A* and *A′* are closed while *B* and *B′* are open and conversely. If *A* and *A′* are closed, the battery is connected across the field so that the field polarity is as shown; if *B* and *B′* are closed, the field has the opposite polarity applied. Thus, this circuit functions similarly to a double-pole, double-throw reversing switch with the one outstanding difference that it can be thrown practically instantaneously. That is, the polarity of the field can be reversed without ever opening the field circuit. Thus, there will be no high-voltage surges and no discontinuities in the current. The average field-current can therefore be controlled by varying the ratio of the time that one polarity of voltage is applied to the field to the time the other polarity is applied. Typical waveforms are shown in the right-hand section of *Fig.* 4. If the frequency of these rectangular voltage waves is very high compared to the reciprocal of the time constant of the field, the field-current will have very little ripple. This bridge can be held closed in either position and, hence, can apply full forcing to the field in either direction. A voltage regulator containing an exciter of this type would essentially contain only one time constant, that of the field winding itself.

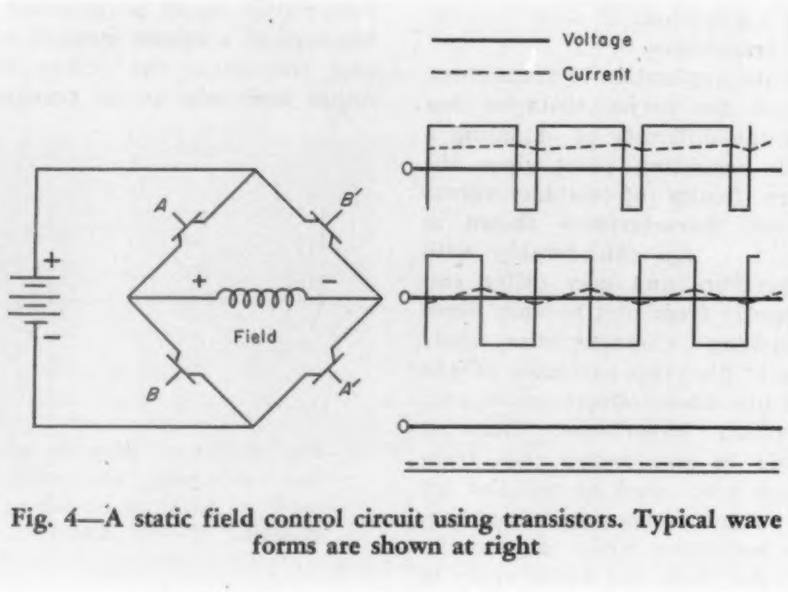

Fig. 4—A static field control circuit using transistors. Typical wave forms are shown at right

Performance Life: Some early types of junction transistors had an unexpectedly high rate of failure. Investigation showed these failures were due primarily to faulty mechanical structure or, more important, moisture reaching the junction. Present techniques have eliminated these difficulties and modern units show promise of very long life. There are few pertinent life test results available today because present designs are only about a year old. Units running continuously for this period have shown almost no failures. The life of transistors should be of the same order as power rectifiers. There are no known factors which would place an upper limit on life as long as the unit is operated within its ratings.

All commercial transistors today are made of germanium and will operate as switches up to temperatures a little above 100 C. It is expected that silicon transistors will be available within the year (silicon diodes are now available) and they will operate in the region of 200 C. Thus, temperature limitations do not appear to be a problem.

It is, of course, too early to give cost estimates on power transistors. However, power diodes are now considerably cheaper than ignitrons of similar current rating, although they are slightly more expensive than ignitrons when compared on a power basis. This is due to the higher voltage rating of the ignitron.

Another entirely different industrial application of transistors and one which is not in the future but is fully practical today, is the use of phototransistors in place of photocells. Transistors of the finger tip size previously described have a photosensitivity only slightly less than that of photomultiplier tubes and far greater than any other available device. They are extremely sensitive to an incandescent lamp even when it is glowing only a dull red. Such phototransistors are in many cases capable of operating quite rugged relays directly, with no intermediate ampli-

fiers, and require only 6 to 12 volt supply. The extreme reliability and small size of this device may open up many more applications of light actuated machine controls.

From a paper entitled "Future Applications of Transistors to Control Machine Tools" presented at the 18th Annual Machine Tool Electrification Forum, sponsored by the Westinghouse Electric Corp., Buffalo, N. Y., April, 1954.

Influence of Manufacturing Methods on

Gear Design

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IN GEARS, as in any other machine element, the actual conditions of operation and the actual dimensional and physical characteristics are subject to deviations from the assumed quality. Type and extent of these deviations produce major differences between assumed and actual characteristics, thus reducing the reliability of analytical data.

Calculation of power capacity of gears is usually based on three major limitations:

1. Static strength of gear teeth, determined by the operating bending stress in the root, and the permissible bending stress of the tooth material in this location.
2. Surface stress at the tooth flanks in mesh, and the ability of the material to resist scuffing, pitting, or plastic flow under the surface stress and sliding velocity involved.
3. Rate of heat generation and ability of gears and cooling lubricant to dissipate heat at a temperature that will not favor deterioration of the material under surface stress and sliding velocity.

Calculation of bending stress is based on a number of assumptions which essentially deviate from actual conditions. Linear increase of stress from a neutral zone to a maximum at the surface is generally not existent on an actual gear tooth under load. Stress concentration at the roof fillet is greatly affected by manufacturing processes. The surface of a carburized gear, for example, has an initial compressive stress which counteracts the operational tensile stress in the outer fiber.

Resistance of the surface of tooth flanks against deterioration under pressure and sliding depends to a great extent on the initial characteristics of the surface, its smoothness, ability to retain lubricant and, most important, its hardness at the extreme outer surface.

Limitations due to heat generation are generally not of decisive nature, as long as adequate pressure lubrication is maintained, and as long as progressive damage of the tooth surfaces does not occur due to physical deficiencies.

Physical and dimensional characteristics are interrelated. The heat-treating methods which produce the desired physical properties of the gear teeth always have the detrimental effect of producing distortions. These distortions occur within the gear teeth as well as within the blank, resulting in deformed teeth, unequal spacing, and ovality and eccentricity of the pitch diameter. In operation, this means localized concentrated tooth loads, periodically changing loads due to accelerations in the rotating motion, and fluctuations of reaction forces on bearings and structures. The resulting increased stresses correspond to reduction of power-transmitting capacity.

Improving Physical Properties: The following processes are available for improving physical properties of gears:

1. Hardening of Entire Gear: Heat-treating the entire gear increases tensile and compressive strength of the teeth, and wear resistance of the tooth surface. If the teeth are finish cut after heat treating, then the hardness is limited to a value acceptable for cutter material and for rigidity of existing machines. A brinell hardness of 230 to 270 is the usual practical range, corresponding to 110,000 to 150,000 psi ultimate tensile strength.

If hardening is done after finish cutting, then the distortions are retained in the gear. If the hardness is brought to a value desirable for wear resistance, then the material will be too brittle for the intermittent bending loads imposed

Table 1—Typical Physical Characteristics of Gears

Physical Characteristics	Type of Gear: Soft	Heat-Treated	Induction or Flame-Hardened	Carburized or Nitrided
Core hardness				
Brinell No.	190	250	280	330
Rockwell C	14	26	30	35
Case hardness				
Rockwell C	14	26	55	60
Tensile strength at outer fiber (1000 psi)	90	125	250	300
Typical allowable bending stress (1000 psi)	15	20	28	40
Typical allowable surface compression stress (1000 psi)	75	90	135	160
Reliable maximum operating pitch-line velocity (1000 fpm)	5	20	30	40

DESIGN ABSTRACTS

on the teeth. Therefore, this process may be used only to a limited degree.

2. Surface Hardening of Gear Teeth: Typical examples of surface treatment are induction hardening and flame hardening. Induction hardening is particularly suited for gears of small and medium size, while flame hardening is used on large gears. The electric induction process heats the surface within a few seconds to a depth of 0.02 to 0.12-inch, and subsequent quenching with water produces a hard surface, leaving the core soft and ductile. Flame hardening is done by heating the teeth with a gas flame, and subsequent water quench. If the material is of the slow-quench type, the water quench may be omitted and the cooling from the adjoining volume of cold metal is sufficient.

The hard surface with soft core is a desirable condition, but the hardened surface usually contains tensile stresses which are detrimental to bending and fatigue resistance. High-carbon steels used for water quench are not the most desirable materials from the viewpoint of uniformity, impact strength, and ductility.

3. Chemical Surface Hardening: The principle of these processes is the use of a grade of steel which normally will not become fully hard, but by application of suitable processes the surface is chemically changed to assume hardenability. Processes of this type are carburizing and nitriding. In carburizing, a low-carbon steel is used, and by sustained heating in a carbon-releasing substance the carbon content of the outer layers is increased. After subsequent quenching the gear has a hard outer case with a ductile core. Depth of the hard case can be controlled accurately by the time of exposure to the carburizing medium, and hardness is independent of case depth. In nitriding, a special alloy steel is used which, when heated at moderate temperatures in a nitrogen atmosphere, undergoes a chemical change in the surface structure, resulting in hardening to about the same degree as obtained in carburizing. Distortions in nitriding are small due to the low temperatures involved, but control of surface hardness and case depth in this process is not equal to that of carburizing, and generally nitriding is only good for small case depths. Both processes provide a compressive stress in the surface which improves fatigue resistance of the gear.

4. Cold Working the Surface: This process imparts a compressive stress to the surface by mechanical pressure exceeding the yield point. The practical method of using this principle on gear teeth is shotpeening, consisting of the action of a large number of small round shot balls hitting the surface with an impact. The effect is

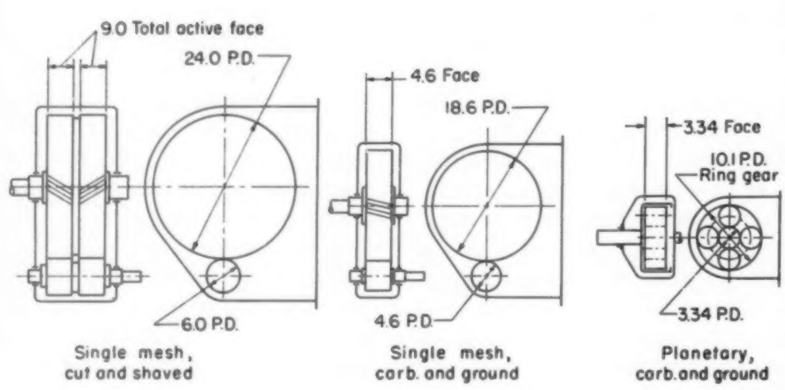
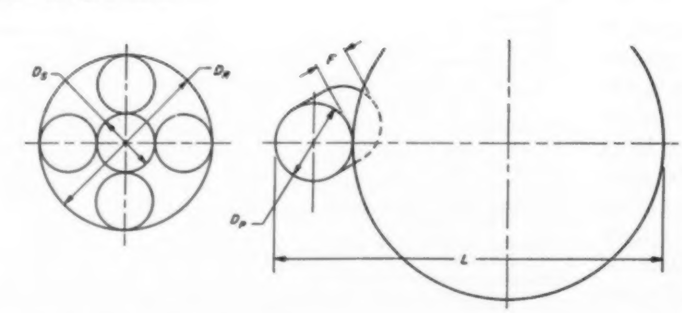


Fig. 1—Comparison of typical gear dimensions for equal power, speed and gear ratio

Table 2—Gear Dimension Comparison*

	Planetary Carburized & Ground						Single Stage Carburized & Ground						Single Stage Cut		
	Spur			Helical			Spur			Helical			Helical		
F/D	D_S	D_R	F	D_S	D_R	F	D_P	L	F	D_P	L	F	D_P	L	F
1/2	4.75	14.25	2.38	4.2	12.6	2.10	6.60	33.0	3.30	5.85	29.20	2.90	8.62	43.10	4.31
1	3.77	11.30	3.80	3.34	10.10	3.34	5.24	26.2	5.24	4.64	23.20	4.64	6.84	34.2	6.84
3/2	3.30	9.90	5.00	2.90	8.70	4.35	4.85	22.9	6.87	4.06	20.30	6.10	6.00	30.0	9.00

*For 1000 hp, 2000 rpm, 4/1 gear ratio.



a compressive stress in a thin surface layer, but there is no gain in hardness. Shotpeening also may be used on carburized or nitrided surfaces, where it sometimes decreases the effect of small surface scratches caused by previous machining.

Comparing Manufacturing Processes: A comparison of physical data of gears made by different processes is shown in *Table* 1. The numerical values in this table should be taken only as typical, not as definite limits. The important difference is in the allowable stresses which determine the size of the gears.

If the designer is free to choose the manufacturing processes for his gears, the dimensions of the entire gear drive may be subject to considerable reductions. Where the distortions of the carburizing process can be corrected by subsequent tooth grinding, the gear will have optimum physical and dimensional characteristics.

Cost of Gears: Where costs of ground gears versus cut gears are compared, the complete design from the initial concept must be taken into consideration. Cut gears, of course, eliminate the cost of carburizing and grinding. However, cut gears will be considerably larger in all dimensions. This means greater cutting cost. For final surface finish and tooth form a shaving operation usually must be performed after cutting. The housing and bearing structure will be more expensive, owing to the increased dimensions, and assembly, shipping and installation will be more costly for a larger and heavier unit. In many cases, the outside dimensions of the gear case may have a limiting influence on the design of the prime mover and the driven machine.

Carburized and ground gears may be designed with considerably smaller dimensions than cut gears, and thus the entire drive will have the economic advantage of a more compact and light unit. Machining cost will be saved on all parts of the drive assembly, cutting cost of the gear teeth will be lower, and shaving is eliminated. The cost of carburizing and tooth-grinding are the only important additions, but they are likely to be more than compensated for by savings in material, machining time and easier handling.

Reduction in Dimensions: Considerable reduction of over-all dimensions of a gear drive can be obtained if the load is distributed over several gear meshes. This is the case in planetary drives, where a number of pinions are arranged concentrically around the sun gear. Illustrated in *Fig.* 1 is a comparison of typical sizes of single-mesh versus planetary drive for an input speed of 2000 rpm, 1000 hp, and 4/1 gear ratio. A comparison of the dimensional data for three different ratios of face width to diameter is shown in *Table* 2.

High-power planetary reduction gears are presently used in some (mostly foreign) installations, and several large units for military applications are under development by American firms. Existing units operate at several thousand horsepower, with input speeds up to around 25,000 rpm. This type of design has been made in gear ratios of about 3/1 to 12/1 in one stage, at power ratings of 20,000 hp and more, with input speeds up to 30,000 rpm. Characteristic for this design is the full-floating mounting of the internal gear, which permits it to align itself with the planets for concentricity and equal load distribution.

Extensive use of carburized and ground gears for reduction drives of high-power ratings is a current trend of development. It may be expected that, particularly in connection with improvement of gas-turbine designs, high-power, high-gear-ratio planetary drives will be manufactured for most stationary and marine applications. Aircraft drives, with gear ratios up to 100/1 in three planetary stages, with several thousand horsepower, have already proved the importance of optimum co-ordination of gear design, manufacturing methods, and quality control.

From a paper entitled "Manufacturing Methods of Power-Transmission Gears and Their Influence on Design Considerations" presented at the ASME Semi-Annual Meeting in Pittsburgh, Pa., June, 1954.

Designing Drives and Controls Using . . .

Electromagnetic Multiple-Disk Clutches

By H. B. Stallings
I-T-E Circuit Breaker Co.
Philadelphia, Pa.

TODAY, the electromagnetic multiple-disk clutch is used in drives for machine tools, special machines such as textile and knitting machines, automatic transmissions for buses and large trucks, and reversing duty for ship propellers. Many other uses are being contemplated, such as overdrives for automobiles, fan drives, cranes and hoists.

Clutch Design: In *Fig.* 1 the main parts of the clutch are shown. On the clutch body, with the imbedded clutch coil, is shown the slip ring, and the brush for conducting current to the coil. Only one brush is used, as one coil lead is connected to the clutch body.

The magnetic flux path is shown in *Fig.* 2. The flux flows transversely through the laminations, which are made of steel with rela-

tively high permeability.

Magnetic flux when the coil is energized causes a pull between the body and armature. The armature is forced against the body and compresses the lamination stack. Torque which the clutch can transmit is a function of magnetic pull (compression force), coefficient of friction between the mating surfaces in the lamination stack and number of mating surfaces in the stack. No external operating force is transmitted to the shafts or bearings, and these parts are thus unaffected by closing force of the clutch. The electromagnetic multiple-disk clutch is self-compensating for lamination wear.

For the clutch to disengage in a reasonable time, laminations must be forced apart after magnetic force is removed. For this reason, one-half of the laminations are wave-formed and act as springs to force the laminations apart. In closing the clutch, magnetic pull must be greater than the spring tension in order to flatten the laminations and obtain maximum torque.

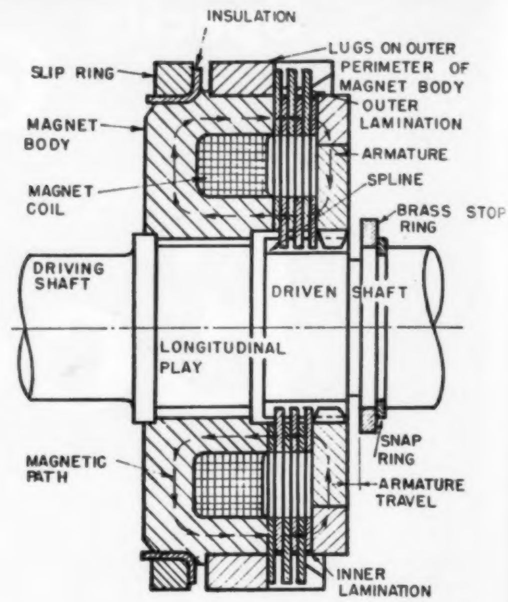


Fig. 2 — Schematic cross section of the clutch

Clutch Operation: Before the clutch coil is energized, the clutch is operating at the residual torque. This torque is present in all laminated clutches. For this clutch residual torque is approximately 1 per cent.

When current is applied, torque increases to the actual starting torque, which is the maximum torque the clutch can start against. This torque is determined by the dynamic coefficient of friction of dry steel surfaces in motion. As speed difference between the lamination surfaces decreases, coefficient of friction increases to the static value. Transition between the two coefficients of friction is not uniform but takes place in a violent oscillating pattern until the laminations lock together. This phenomenon makes the electromagnetic multiple-disk clutch abrupt in its closing operation. When soft engagement is a requirement it should not be used, or special consideration should be given to the control circuit of the clutch.

On opening the coil circuit, current decays very rapidly. However, transmitted torque is maintained for 0.055-second because the laminations must be forced apart.

Operation time of the clutch when closing can be divided into two parts. First is the closing time, which is the time from the energizing of the clutch coil until the air gap is closed. Second is the clutching time, which is the time from air gap closing to the time laminations are locked together.

Closing time is constant for any clutch type or rating. Clutch time is variable and depends on the flywheel effects of the parts being accelerated and the steady-state load torque the clutch must transmit during starting.

During clutching time, load of the clutch always reaches the maximum starting torque. If steady-state torque of the clutch is high, torque available for acceleration of the masses to be started is small and therefore the clutching time becomes long. If useful torque transmitted by the clutch is equal to or greater than starting torque, starting time will be infinite.

Time-torque curves shown in

Fig. 1—Expanded view of electromagnetic multiple-disk clutch showing, from the left to right, the armature, the lamination stack, an inner lamination, an outer lamination and the clutch body

Fig. 3 are determined from the following formula for clutching time:

$$t = \frac{Wr^2n}{44{,}300\ (T_s - T_l)}$$

where

t = time, seconds
Wr^2 = flywheel effect of accelerated parts, lb-in^2
$n = (n_1 - n_2)$ = differences in speed before and after clutching, rpm
T_s = maximum starting torque, lb-ft
T_l = steady-state load torque, lb-ft

To this clutching time must be added the closing time to obtain total engaging time of the clutch.

Curves are drawn for a clutch with a rated starting torque of 70 lb-ft. Peak starting torque is 70 per cent higher or 120 lb-ft, but as this ultimate value varies somewhat from clutch to clutch, a value of 100 lb-ft has been used in the formula as T_s, giving margin of safety of approximately 20 to 25 per cent. Curves are drawn for a speed differential of 1000 rpm. If the steady-state load torque varies between 0-70 lb-ft and the flywheel effect is small, total operating time varies very little. Above a steady-state load torque of 70 lb-ft the curve flattens out very rapidly and the operating time becomes long. As most clutches in a rough sort of a way should not exceed a clutching time of 1½ seconds, it is recommended not to use this clutch for a steady-state load torque over 70 lb-ft. As is very often the case in machine tools, the machine is started up without load (cutting). In this case a flywheel effect of 6650 lb-in.^{2} can be accelerated after which the machine can be loaded safely to 140 lb-ft steady-state torque.

These calculations show what the clutch can handle as far as a complete start is concerned, but it does not show how often a start can be made. This is of course determined by how well heat developed during the start is removed from the clutch. Maximum operating temperature of the coil is 125 C and of the clutch lamination approximately 200 C. Temperature above this limit eventually will cause permanent damage to the clutch.

When multiple-disk electromagnetic clutches are used for changing speeds, time required for the speed change can be determined by adding time of opening and closing together, and adding any time delay between control currents of the opening and closing circuit.

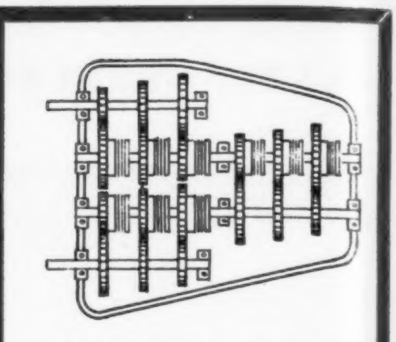


Fig. 4—Gear transmission for 27 output speeds using nine electromagnetic clutches

With an induction-motor drive starting torque of the clutch should be equal to rated torque of the motor. However, if this drive is overloaded by accident, some means to protect the clutches is needed, e.g., by a shear pin or some other clutching means opening under overload. Otherwise, the clutch might slip before the motor reaches its stalling torque and permanent damage might be done to the clutch.

Drive Applications: By using a combination of clutches and gears a drive can be produced which will deliver several fixed output speeds with a constant input speed. In *Fig.* 4 is a simple gear box with 27 different output speeds utilizing only nine clutches. There are no sliding gears or any other mechanical clutching means. Output speeds are obtained automatically by proper electrical control circuits and without stopping the machine.

Many other gears and clutch combinations are, of course, possible and any number of speed variations can be obtained by proper selection of the gears, *Fig.* 5. The only limiting factor is that care must be taken that none of the clutches operate at a greater differential speed than that specified by the manufacturer.

Further refinement can be made by using multiple-speed motors, and the drive can be reversed either by installation of reversing gears with clutches or by reversing the motor. If two clutches on the same shaft are energized simultaneously, breaking action will take place. Thus gear boxes

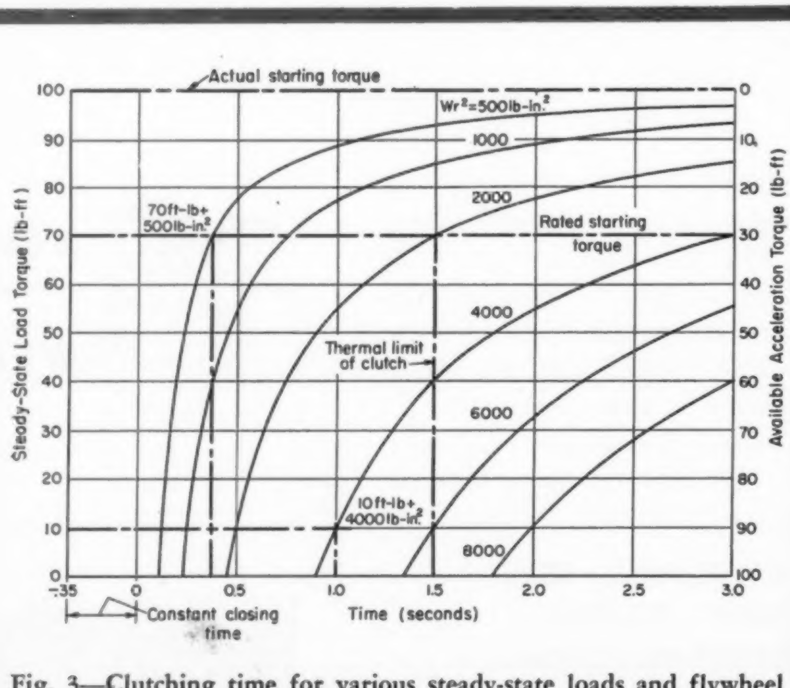
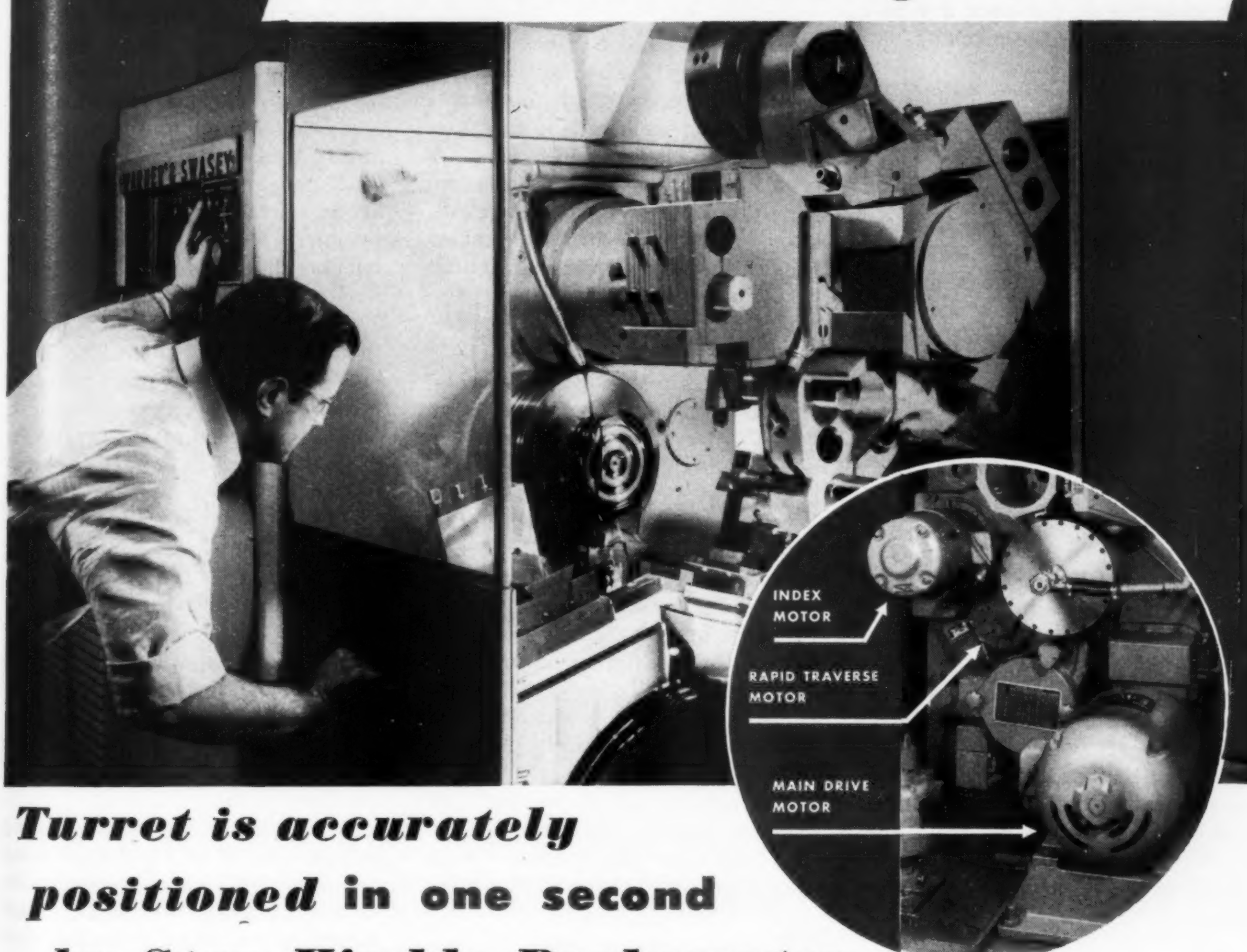


Fig. 3—Clutching time for various steady-state loads and flywheel effects. Differential speed n = 1000 rpm

On the NEW Warner & Swasey Automatic Chucking Machine



Turret is accurately positioned in one second *by Star-Kimble Brakemotor*

Turret of this production-speeding Warner & Swasey 2AC Machine—with turret-and-tool weight of 1250 pounds—is rotated 72° after each operation by a standard 1 hp Star-Kimble Brakemotor . . . and is accurately positioned for the next operation *within 1 second!* Fast, time-after-time precision stops of the Star-Kimble design make this possible.

FOR THE RAPID TRAVERSE, too—calling for turret-and-tool movement at 4 inches per second, with a maximum of 10 starts and stops in 45 seconds—Warner & Swasey has selected a completely special Star-Kimble 1½ hp construction designed both for this severe service and for the limited space available in the machine column.

AND FOR THE MAIN DRIVE MOTOR, which is selected by the customer, many purchasers of 2AC automatic chucking machines are specifying a 15 hp Star-Kimble dripproof squirrel-cage motor of basically standard construction, with special electrical characteristics specifically designed for this application.

These three types of motors are typical of Star-Kimble's ability to supply: standard motors for which all parts and subassemblies are carried in stock; modified types which can be economically produced in small quantities; and completely special designs in volume runs. Your inquiries on your specific requirements are invited.

Standard and special motors of all types, 1 to 125 hp; generators and motor-generator sets, 1 to 100 kw; marine motors, ½ to 125 hp.

Star-Kimble MOTOR DIVISION

MIEHLE PRINTING PRESS & MFG. CO.

201 Bloomfield Avenue **Bloomfield, New Jersey**

equipped with multiple electromagnetic clutches do not need a separate brake to stop the machine.

Control: Watt consumption of these clutches is so small that telephone relays can be used for control. This offers advantages in machine-tool control because the telephone relay, besides being small, is very reliable. Furthermore, telephone relays can be obtained with all kinds of contact combinations and time delays, on closing or opening, or both. Stepping relays can be used for proper sequential operation, and maintenance of such a control system becomes extremely simple if plug-in type relays are placed in the clutch circuits.

Oiling and Cooling the Clutch: The clutch is designed to operate under oily conditions. Oiling of the clutch can be done by drip, spray, fog or running the clutch slightly submerged in oil. Heat dissipation from the clutch can be increased materially if the clutch is lubricated by using a hollow shaft and radiating oil from the hollow center to passages distributing oil to the inside of the laminations. From here centrifugal force will force the oil through the laminations to the outside surfaces.

Slip Ring and Brushes: The problem of transferring current from a stationary brush to a moving slip ring under oily conditions is a formidable one and is the one problem which has not been completely solved. As oil is an insulator, electrical current cannot pass through an oil film. If arcing takes place both the brush and slip ring are very quickly destroyed.

A practical solution to the problem is to use brushes made from very fine woven metallic wire mesh and then arrange two brushes concentric with each other. Both brushes make contact with the slip ring and each brush is forced against the slip ring by independent springs. As the masses of the brushes are different, the two brushes have different natural frequencies of oscillation and the possibility of both brushes leaving the slip ring simultaneously is very slight. Furthermore the outer brush acts as an oil scraper and removes the oil film from the slip ring so that the center brush makes metallic connection under dry surface conditions.

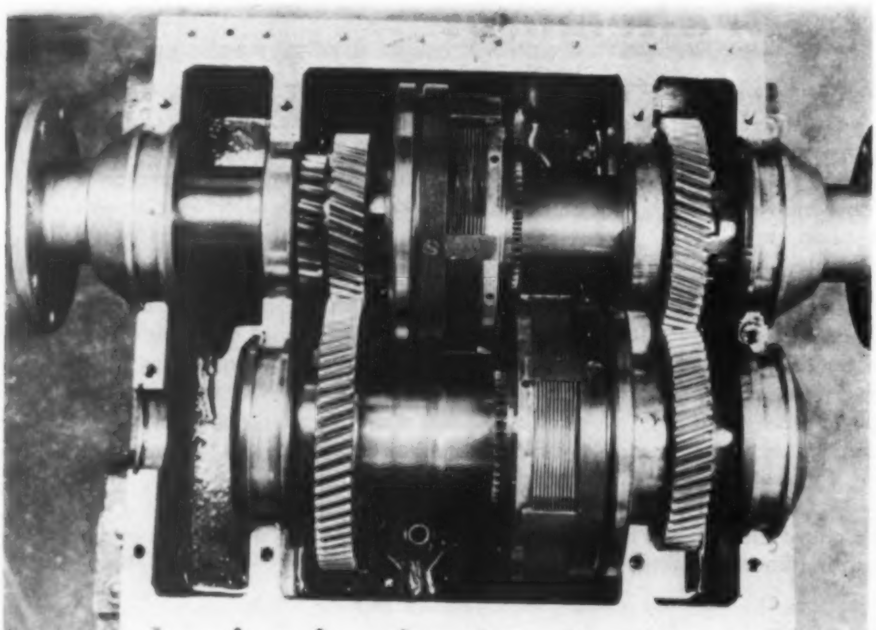


Fig. 5—Top view of two-speed gear box—input at left, output at right. Energizing upper clutch permits direct drive; energizing lower clutch permits drive through back gear

Control Circuits: Since the clutch is only supplied with one slip ring it has been the practice on the Continent to let the coil current return to the power source by means of the shaft on which the clutch is mounted and through the antifriction bearing locating the shaft in the gear housing. This arrangement has given very little trouble. Manufacturers of antifriction bearings in the United States, however, have taken the standpoint that if current is passed through their bearings, the bearings are no longer guaranteed by them. Actually, an antifriction bearing is a good conductor of current provided that metallic connection is always present between the races and the ball or rollers, depending on what type of bearing is used.

Just to bypass the bearings by means of a grounded brush on the shaft will not eliminate the current flowing through the bearings. Return current will divide itself between the two paths in inverse relationship to the resistance of the two paths.

A simple method of eliminating all possibility of current flowing over the antifriction bearing is obtained by using one single brush riding on the shaft mounting several clutches. This brush must be insulated from the gear-case housing and connected directly to the current source of the clutch. In all events the casing of the machine is grounded as a safety measure but this grounding of the case does not permit current to flow over the bearing as long as the current source is insulated from the case.

To avoid any possibility of leakage current through the bearing when several shafts equipped with clutches are mounted in the same housing, a separate current source should be used for the clutches mounted on each separate shaft. Current source is usually a small dry-type rectifier fed by a small transformer connected to the incoming line to the machine.

From a paper entitled "The Electromagnetic Clutch—Its Operation, Application and Control" presented at the ASME Fall Meeting in Milwaukee, Wis., September, 1954.

Helpful Literature

(*Continued from Page* 298)

38. Tubes & Tubular Assemblies

Elano Corp.—Facilities for producing formed tubes and tubular assemblies are covered in illustrated 4-page bulletin. Examples of various assemblies are shown.

39. Powder Metallurgy

National Radiator Co., Plastic Metals Div.—Brief introduction to art of powder metallurgy is provided by 4-page bulletin No. 1. It describes general types of metal powder offered by company, stresses large number of grades required for different applications and lists some of uses for metal powders.

40. Thermostatic Slide Rule

Mechanical Industries Production Co.—Suitable formulas for calculating applications for Mighty-Mite thermostats are found on this slide rule. It incorporates all nine standard scales, including C1 reciprocals, and measures 10 x 4 in. Trigonometric formulae for right triangles, sines and limits of value and other settings are included.

41. Precision Cams

Ford Instrument Co.—Wide variety of types and sizes of cams for practically any kind of application are described in 4-page illustrated bulletin CB-754. Two groupings are covered: three-dimensional (two inputs) and single-input cams. Construction, application and general data are provided. Production facilities are detailed.

42. Rockwell Hardness Testers

American Chain & Cable Co., Mechanical Instrument Div.—Engineering, use and design data found in comprehensive, illustrated catalog covers a normal hardness tester, superficial tester, accessory and special tester and micro and macro hardness testing units. Testers handle all types of metals and alloys, hard or soft, polished or unpolished, flat, round, or irregular.

43. Handles & Clips

E. H. Titchener & Co.—Full size illustrations of 73 different styles and types of standard handles and clips are shown in 20-page handbook "Wire Handles by Titchener." A wire size chart shows actual diameters of standard wire gages.

44. Power Transmission Equipment

American Pulley Co.—Brief descriptions of Wedgbelt and Shaft-King speed reduction drives, adjustable speed sheaves, steel split pulleys, conveyor pulleys, Econ-O-Matic motor bases, individual cotton card drives, Hi-Torque pulleys, collars and shaft hangers are found in 4-page illustrated bulletin "Power Transmission by American."

45. Special Electrical Components

Ram Meter, Inc.—Special purpose electrical, electro-mechanical or electronic components and devices, none of which are stocked, are subject of illustrated brochure P54. Typical examples are described and specific results specified for them are given.

46. Snap Action Switches

Acro Mfg. Co., Acro-Mu Switch Div.—36-page illustrated catalog No. 98 contains general data, engineering information and specifications for extensive line of snap-action switches. Various types of actuations, mountings and brackets are detailed.

47. Needle Valves

Foxboro Co.—Design details and operating characteristics of line of needle type valves are explained in 8-page bulletin 5C-13. Valves are designed for precise control of low flow rates. Table of nominal needle sizes with corresponding valve coefficients and formulas for calculating valve size for use with liquids, gases and steam are included.

48. Pilot Bearing Bushings

Donley Products, Inc., J. G. Jergens Div.—Precision piloting applications of Jergens live bushings on boring mills, radial drill presses, and milling machines are illustrated in 8-page catalog which features questions and answers on uses and performance features. Absolute seal principle is described as well.

49. Ball-Bearing Swivel Joints

Chiksan Co.—32-page catalog G-4 covers complete line of ball-bearing swivel joints, loading racks, manifolding lines, all-metal marine and barge hose and flexible aircraft assemblies. In addition to dimensional and operating data, piece illustrates typical industrial application of this equipment.

50. Work Holding Fixtures

Jefferson Corp., Swartz Tool Products Div.—Precision work holding fixtures for use on in-line transfer machines, rotary and trunnion index machines, single station machines are subject of 8-page illustrated bulletin. Various installations are shown. In addition to designing and building special fixtures company also makes line of standard pump jigs, fixtures and fixture locks.

51. Centrifugal Pumps

Gorman-Rupp Co. — O series of centrifugal pumps that prime is described in illustrated 12-page bulletin 4-PP-11. Cutaway drawings show design and operation. Units are available for vertical, power take-off, gasoline engine, and flexible coupling drives. Engineering information, specifications and selection tables are included.

52. Servo Motors

G-M Laboratories Inc.—Sizes of servo motors and tachometer generators listed in 4-page illustrated catalog No. 4 range from 0.980 to 1.70-in. diameter and are for use on 60 and 400 cycles at voltages from 26 to 115. Specifications are given.

53. Air Conditioning Equipment

A-P Controls Corp.—Latest information relative to A-P line of valves, filters and dryers for the air conditioning and refrigeration industry is found in condensed catalog W-2-S. Complete product specifications, charts, how-to-select information and sales data are provided.

54. Electric Motor Controls

Furnas Electric Co.—140-page electric motor control catalog No. 101 lists more than 2700 items among which are magnetic starters and contactors, combination starters, control panels, drum controllers and master, foot and pressure switches. Primarily divided by major classifications, catalog contains engineering and design data, including wiring diagrams.

55. Roller Chain & Sprockets

Diamond Chain Co.—"Stock Roller Chain and Sprockets" is title of 64-page illustrated catalog 754 which covers a complete line of these items. Line includes minimum bore sprockets for reboring as well as finished bore and Taper-Lock bushed sprockets which are ready to use. Chain selection and application data are included in the catalog.

56. Engines & Power Units

International Harvester Co. — Complete specifications, performance data and general description of five four-cylinder, four-cycle International engines are provided in 12-page bulletin CR-355-A. Models covered are 16.5, 24, 31.5, 41 and 55-hp units which will operate on gasoline, natural gas, distillate or kerosene.

57. Clutches & Drives

Twin Disc Clutch Co.—"Production Road" magazine features highlights of Twin Disc textile machinery drives and gives details on the Hydro-tensor, a loom let-off, and model PT air-actuated loom friction clutch, as well as the Hydro-Wynd and Hydro-Sheave drives. Other sections feature stories on powered equipment used by various basic industries.

58. Solenoids & Relays

G. H. Leland, Inc.—Typical applications for Ledex rotary solenoids and relays are described in 6-page bulletin 354. Highlights include drawings of standard and special features, a torque chart and dimensional drawings of foot and flange mounted relays made from stock parts.

59. Relief Valves

Fluid Control, Inc.—Catalog sheets describing line of differential piston-type relief valves are available along with diagram illustrating their use in typical circuit. Valve is recommended for critical applications in which failure to hold pressure is hazardous.

60. Gears, Sprockets, Shafts

Penn Machine Co.—Details of company's planning procedures, engineering facilities, testing and inspection processes are included in 24-page brochure. Company specializes in gears, sprockets, shafts, bronze castings and similar parts.

61. Worm Gear Drives

Cleveland Worm & Gear Co.— "Keep 'Em Rolling" is title of 8-page bulletin which illustrates application of worm gear drives and speed reducers in steel mill runout tables, hydraulic cutter dredges, lacquer mixing tanks, feeder tables and bending rolls.

62. Four-Cylinder Engines

Willys Motors Inc.—Specifications, features and dimensions relative to two four-cylinder industrial engines are given in 6-page folder W4-LM. An L-head model which develops 60 hp at 3600 rpm and an F-head engine which is rated 70 hp at 4000 rpm are described.

63. Vulcanized Fibre

National Vulcanized Fibre Co. — Featured characteristics of vulcanized fiber, a rough, resilient plastic with great mechanical strength and good electrical properties are pointed out in 8-page booklet "Meet 'Sherlock' Fibre." Material is offered in sheet, rod and tube form as well as in finished component parts.

64. Shaded Pole Motors

General Electric Co.—Line of shaded-pole fractional horsepower motors for fan and blower applications is described in 10-page bulletin GEA-6134. It illustrates features and applications of these units rated from 1.5 w through 1/6-hp and gives complete specifications and operating characteristics.

65. Six Contact Connector

DeJUR-Amsco Corp.—Schematics, mechanical and electrical ratings and detailed description of the FHL-6 high voltage, six-contact connector are provided in 2-page data sheet 12D. Voltage breakdown at sea level is 4000 v rms, at 60,000 ft, 1800 v rms.

66. Hydraulic Equipment

Detroit Harvester Co., Warner Hydraulics Div.—Company facilities for design, development and manufacture of precision hydraulic equipment are illustrated in 6-page folder. Services include product design and development, production assembly and testing and precision machining of intricate parts.

67. In-Line Valves

Numatics Operating Valve—New line of Numatic in-line valves with two and three-way normally open and normally closed actions are introduced in illustrated 8-page bulletin 4010-4070. Valves are solenoid-controlled, pilot-operated or remote air pilot-controlled and come in ¼, ⅜, ½, ¾ and 1-in. sizes.

68. High Pressure Valves

Atkomatic Valve Co.—Features of bronze or stainless steel pilot operated and direct lift solenoid valves for high pressure applications are illustrated in 4-page bulletin HP 201. Operating pressures range up to 5000 psi at 150° F and 2500 psi at 450° F.

69. Rotary Air Motors, Pumps

Gast Mfg. Corp.—26 product problems solved with rotary design air motors, compressors and vacuum pumps are featured in 12-page bulletin 449. Booklet is intended as an idea source to aid design engineers.

NEW PARTS AND MATERIALS

For additional information on these new developments, see Page 297

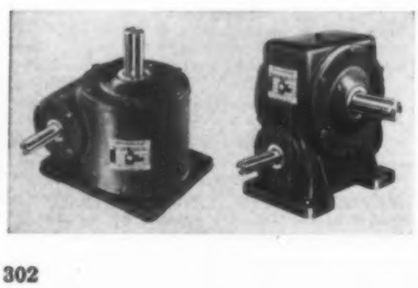
Locknut

Tooth-like elements in the flanged base of this washer type locknut pierce nonconducting materials to achieve an electrically grounded assembly. One-piece locknut and flat washer exerts a double locking spring action on the screw threads. Teeth of the washer engage the metal seat. Fasteners are available in No. 10-24 and ¼-in.-20 sizes. Made by **Palnut Co.,** 61 Cordier St., Irvington 11, N. J.

For more data circle MD-70, Page 297

Speed Reducers

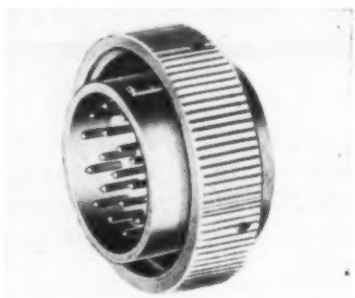
Compact worm gear speed reducers have large capacity. CB, CT and CV designs are each made in 13 sizes. First five sizes in 1/100 to 5-hp range, in ratios from 5:1 to 60:1, are now available, and others will be in production soon. All fulfill AGMA standards, having gears, bearings and shafts rated for AGMA Class 1 service. Surface area provides ample heat radiating capacity. Made by **Winsmith Inc.,** 10 Eaton St., Springville, N. Y.



For more data circle MD-71, Page 297

Miniature Connectors

Shell types available in series K connector line include straight, 90-deg angle and 45-deg angle plugs, all with integral clamps. A standard KO2 box mounting receptacle and hermetically sealed receptacles with steel shells are also available. Shells for plugs, receptacles and endbells are lightweight aluminum alloy, contacts are gold-plated copper alloy, and insulators are nylon. Current rating is 5 amp. Inserts are currently available with 10, 20 and 30-contact arrangements. Connectors withstand temperatures from —67 to 185 F and are resistant to moisture, corrosion and vibration. They meet MIL-E-5272A and MIL-C-5015B specifications. Made by **Cannon Electric Co.,** 3209 Humboldt St., Los Angeles 31, Calif.

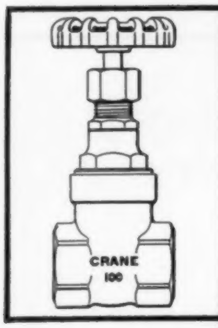


For more data circle MD-72, Page 297

Motor Restarter

Type OFC time delay pushbutton station Condulet restarts motors automatically if starter disconnects because of low voltage or voltage failure. Device is preset to operate within time limits of 2, 4 or 6 seconds. Designed for use in hazardous locations, device is explosion-proof and dust-tight. Pushbutton switch, capacitor, rectifier, sensitive relay and control relay are incorporated in the device, and a transformer for voltages exceeding 110 is supplied, with capacities of 220, 440 and 550 v. Internal wiring includes two terminal blocks, one for field connections and another marked for 2, 4, and 6 seconds to determine time delay. Body of the device has vertical through-feed hubs for

NEW* brass gate valves by CRANE



No. 410,
100-Pound

No. 438,
125-Pound

* NEW SHAPE... NEW STRENGTH

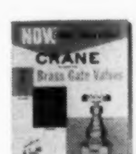
No. 437,
150-Pound

for 3 All-Time CRANE *favorites*

Here are valves that didn't have to be changed . . . because each has long been the best in its class. But Crane found ways of improvement to give you an even better buy for your brass valve dollars.

For example—here is greater strength, greater rigidity, made possible by the new cylindrical upper body . . . the same basic shape as high-pressure steel valves. Here, too, is an improved stuffing box that screws *into* the bonnet—also better stem support to assure truer alignment and minimize wear on the packing.

And not to be overlooked is their clean, modern appearance—a very desirable advantage for all of your "exposed" installations. Sizes ¼ to 3 in. Ask your Crane Representative all about this improved brass valve line next time he calls.

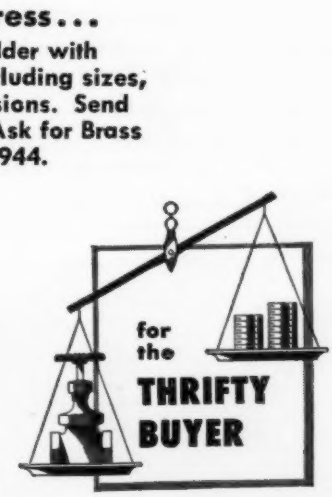


just off the press . . .
new four-page folder with complete facts including sizes, prices and dimensions. Send for yours today. Ask for Brass Valve Folder AD1944.

THE BETTER QUALITY... BIGGER VALUE LINE... IN BRASS, STEEL, IRON

CRANE VALVES

CRANE CO., *General Offices:* 836 S. Michigan Ave., Chicago 5, Illinois
Branches and Wholesalers Serving All Industrial Areas



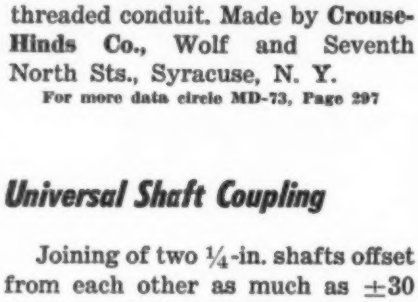
VALVES · FITTINGS · PIPE · PLUMBING · HEATING

threaded conduit. Made by **Crouse-Hinds Co.**, Wolf and Seventh North Sts., Syracuse, N. Y.

For more data circle MD-73, Page 297

Universal Shaft Coupling

Joining of two 1/4-in. shafts offset from each other as much as ±30 degrees and separated by more than



3 in. is possible with this insulated universal shaft coupling. Molded of nylon with nickel-plated brass inserts, the zero-backlash coupling is suitable for use in mechanical, electro-mechanical and electronic equipment. Made by **Jan Hardware Mfg. Co. Inc.**, 75 N. Eleventh St., Brooklyn 11, N. Y.

For more data circle MD-74, Page 297

Air Motor

Cylinder, four-way valve and wide variety of valve controls are combined in compact Lehigh air motor which requires only one connection to air source. Unit's sealed-in lubrication system consists of oil-filled, hollow pistons sealed at the factory. Built-in valve can be operated manually or by air or electricity, or different means in each direction. Motor is available in bores of 1 1/2, 2 or 3 in. with any desired stroke. Valve body is

bronze, valve piston is stainless steel, and bearing bronze slide valve moves on a steel bar stock base. Motors can be furnished with or without adjustable cushions at either or both ends of the cylinder. All have adjustable vane speed control in both directions. Nine mountings are available and operation can be on air up to 200 psi. Made by Air Control Div., **Lehigh Foundries Inc.**, 1500 Lehigh Dr., Easton, Pa.

For more data circle MD-75, Page 297

Motor Pulley

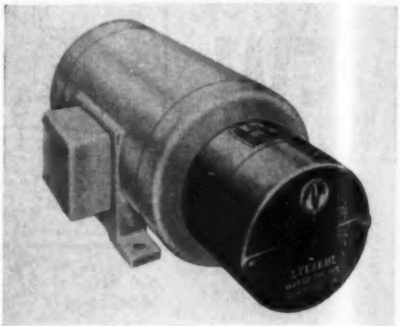
Suitable for use on various types of machinery requiring infinite and automatic variable speed, No. 30 Var' A' Cone variable-pitch motor pulley is small and compact. Unit offers 2 to 1 speed ratio up to 1/3-hp at 1750 rpm. Machined of cast iron, pulley uses A-section belts and has oil-impregnated bearings. Through-shaft mounting is easily

accomplished. Made by **Gerbing Mfg. Corp.**, 11800 Milwaukee Ave., Northbrook, Ill.

For more data circle MD-76, Page 297

Magnetic Disk Brake

For use on NEMA rerated 3 to 20-hp motors, H-70 magnetic disk brake is available in maximum torque ratings of 10, 15, 25, 35, 50, 70, 75 and 105 lb-ft. It is designed to mount on new frame sizes 213 through 286 and is up to 15/16-in. shorter than previous brakes. Brake has manual release-automatic reset wear indicator. The spring-set, solenoid-released brake is supplied for

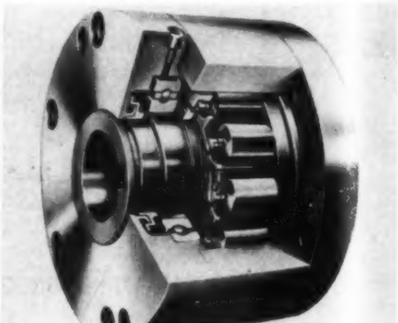


either horizontal or vertical motor mounting or independent floor mounting and can have standard or dust-tight, waterproof enclosures. Made by **Stearns Magnetic Inc.**, 653 S. 28th St., Milwaukee 46, Wis.

For more data circle MD-77, Page 297

Overrunning Clutches

Four standard sizes comprise line of series K extra heavy duty ball bearing overrunning clutches for indexing, backstop and machinery applications. Each has made-to-order bore and keyway sizes, the largest of which can be bored for shafts up to 5 in. diameter. Torque ratings for four models range from 1300 to 8000 lb-ft indexing, 2500 to 15,000 lb-ft general duty and 3000 to 20,000 lb-ft backstop. Typical applications are dual, two-speed, centrifugal water pump, and forced or induced fan drives. Holes are tapped in both ends for attaching sprockets, gears, pulleys or ratchet arms for

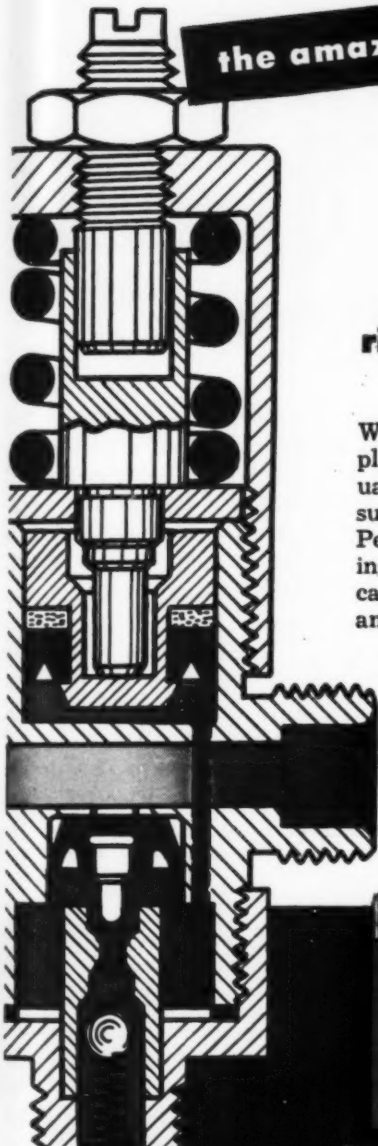


drive requirements from 1300 to 6000 lb-ft. Desired direction of rotation is obtained by attaching component to either side of the

the amazing "lubrication fitting" that thinks ahead...

ALEMITE Accumeter®

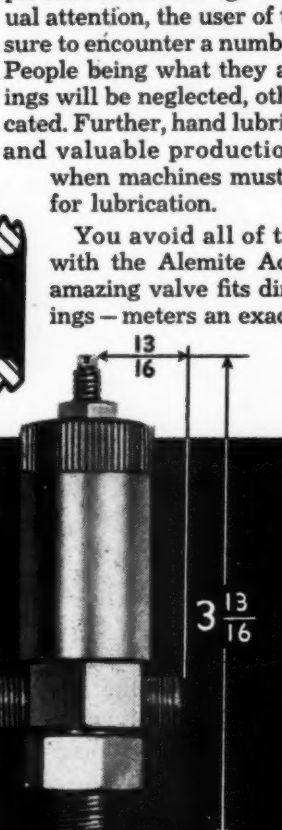
lets you design automatic, fool-proof lubrication right into any machine—simply, economically...offers the operating savings industry will buy!



When a machine is designed with multiple lubrication fittings that require manual attention, the user of that machine is sure to encounter a number of problems. People being what they are, some bearings will be neglected, others over-lubricated. Further, hand lubrication is costly and valuable production time is lost when machines must be shut down for lubrication.

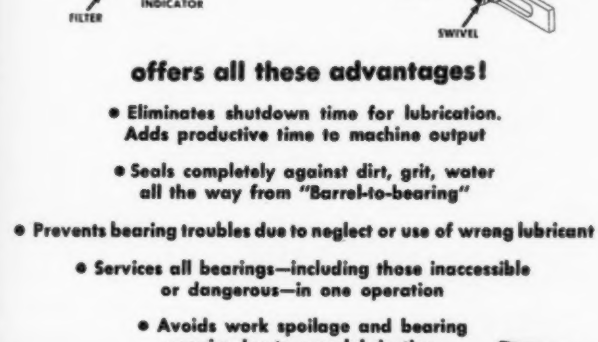
You avoid all of these troubles with the Alemite Accumeter. This amazing valve fits directly on bearings – meters an exact shot of oil or grease *automatically – at pre-determined intervals – while the machine is in operation!* Time, production and maintenance costs are cut to the bone! With all these advantages, it is small wonder that 95% of all major plants buying machine tools specify centralized lubrication.

The Alemite Accumeter system is simple to design and build into any machine. Automatic Accumeter Systems assure you positive, low-cost lubrication. Find out about these automatic systems now. See the savings, the efficiency they add and you too will specify Accumeter!



Type 1 Accumeter Valves

For fluid oil or light grease. In three sizes, delivering from .005 to .050 cu. in. of lubricant. Spring pressure provides gradual feed. Adjustable or fixed output. System serves up to 400 bearings. Either manual or automatic operation available.



offers all these advantages!

- Eliminates shutdown time for lubrication. Adds productive time to machine output
- Seals completely against dirt, grit, water all the way from "Barrel-to-bearing"
- Prevents bearing troubles due to neglect or use of wrong lubricant
- Services all bearings—including those inaccessible or dangerous—in one operation
- Avoids work spoilage and bearing repairs due to over-lubrication

factory tested—field proved

Exhaustive, in-the-field tests show no appreciable variation in the amount of lubricant discharged after 73,312 lubrication cycles—*equal to* 122 YEARS *of twice-a-day service!*

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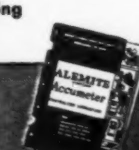
A PRODUCT OF SW STEWART WARNER



Free—*Alemite Accumeter Catalogue and Engineering Data Book.*

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Please send me my free copy of the Alemite Accumeter Catalogue and Engineering Data Book.

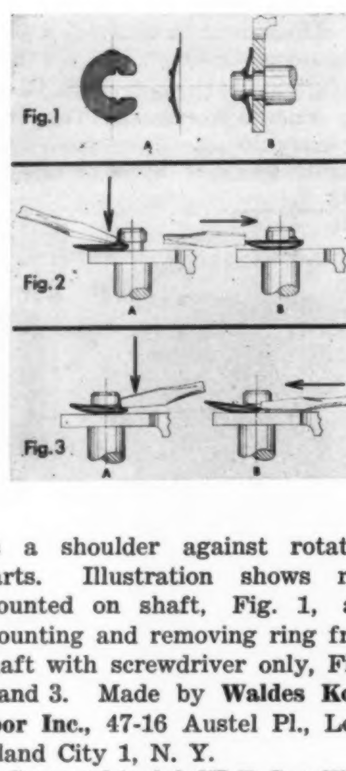
Name
Company
City State

clutch. Made by **Morse Chain Co.**, 7601 Central Ave., Detroit 10, Mich.

For more data circle MD-78, Page 297

Retaining Rings

Two prongs extending from inner circumference of the open end lock this Truarc radially-applied series 5139 retaining ring in its groove when fastened to a shaft. Spring steel ring has shape of bowed horseshoe. Sizes to accommodate shafts from 1/8 to 1/2-in. are standard, and shear strength ranges from 500 to 2500 lb. Fastener is positive-locking against radial displacement, permitting use

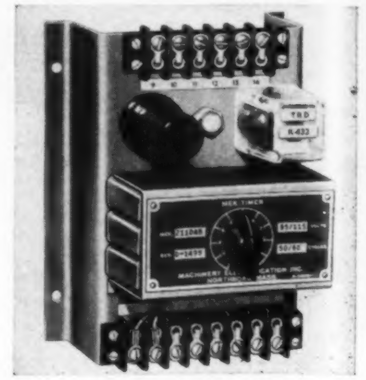


as a shoulder against rotating parts. Illustration shows ring mounted on shaft, Fig. 1, and mounting and removing ring from shaft with screwdriver only, Figs. 2 and 3. Made by **Waldes Kohinoor Inc.**, 47-16 Austel Pl., Long Island City 1, N. Y.

For more data circle MD-79, Page 297

Time Delay Relay

Timing ranges of 1.5 to 120 seconds or 0.75 to 60 seconds are available in model MEK-2110 electronic time delay relay. Double-pole, double-throw load contacts, rated at 5 amp, 115 v ac, are provided for control of external circuits. Repetitive accuracy, with constant line voltage, exceeds ±2 per cent. Factory-set calibration



control compensates for variations due to tolerances in components. Load contacts can be de-energized during reset and timing and energized when "timed out," or this sequence of operation can be altered. Sequences are obtained by interchanging terminal strip connections. Two or more relays can be connected together for complex timing sequences, and open or enclosed forms, as well as remotely adjustable units, are available. Made by **Machinery Electrification Inc.**, Northboro, Mass.

For more data circle MD-80, Page 297

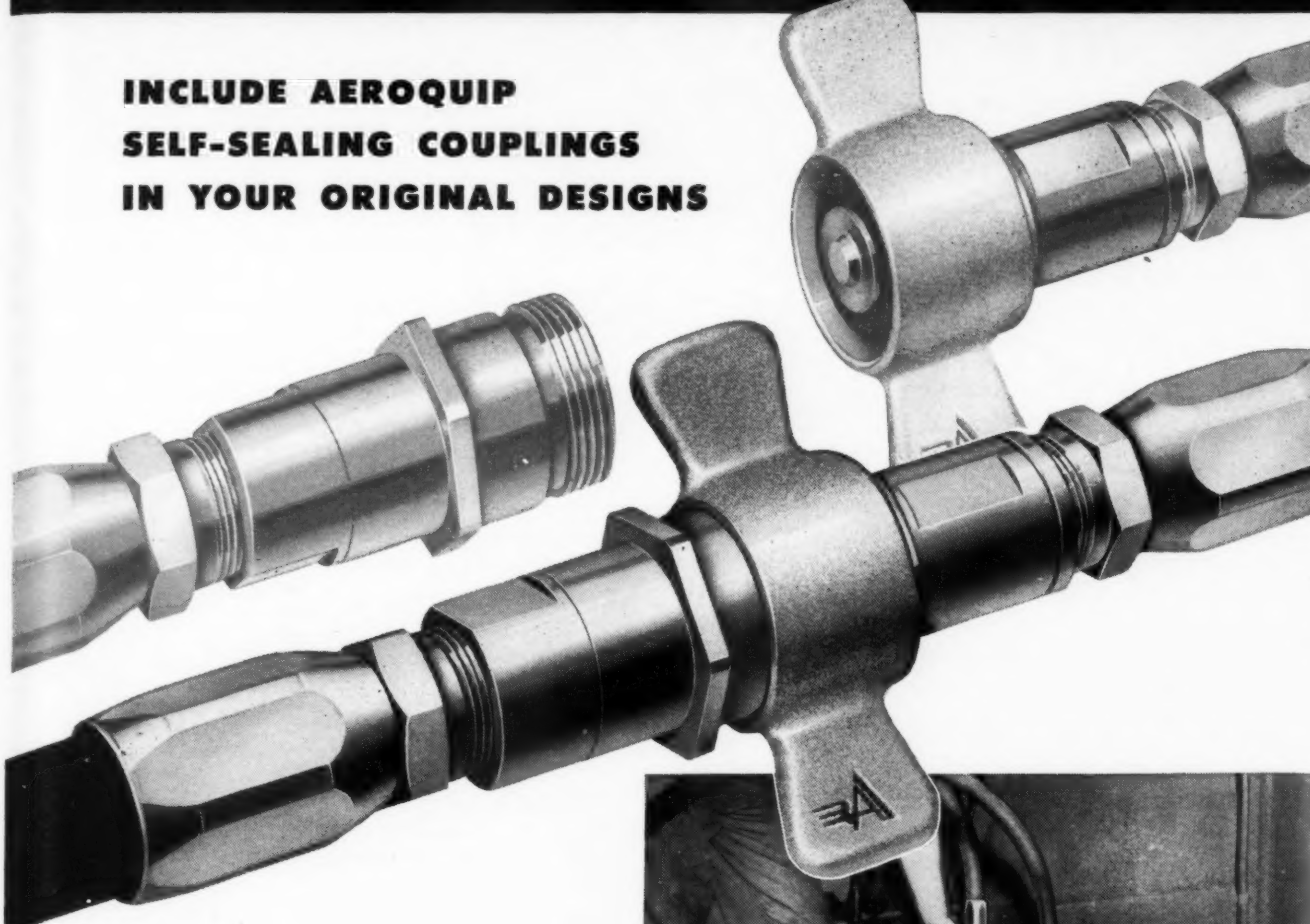
Solenoid Valves

Compact, two-way solenoid valves, for controlling flow of air, gas, water, light oil and other non-corrosive fluids, are available normally closed or normally open. Standard, watertight or explosion-proof enclosures are used. Normally closed model measures 3 13/16-in. high and 2 3/4-in. face-to-face.

They can be used on all standard dc and ac voltages, and have a 10-w power consumption. Maximum pressure rating is 250 psi on air.

For Quick, Easy Changes of Attachments Without Bleeding Hydraulic Lines

INCLUDE AEROQUIP SELF-SEALING COUPLINGS IN YOUR ORIGINAL DESIGNS



Avoid the need for two shut-off valves. One compact Aeroquip self-sealing coupling does the job better. Pressurized hydraulic lines may be disconnected and reconnected instantly . . . no fluid gets out . . . no air gets in . . . interchange of hydraulic attachments is quick and easy.

Aeroquip self-sealing couplings are also recommended for air, oils, fuels, coolants and other fluid lines. See your distributor or write us for information.

Aeroquip Self-Sealing Couplings are used to connect and disconnect pressure and return lines between tractor and trailer with hydraulic dump.

Aeroquip

REG. TRADE MARK

AEROQUIP CORPORATION, JACKSON, MICHIGAN

LOCAL REPRESENTATIVES IN PRINCIPAL CITIES IN U.S.A. AND ABROAD • AEROQUIP PRODUCTS ARE FULLY PROTECTED BY PATENTS IN U.S.A. AND ABROAD

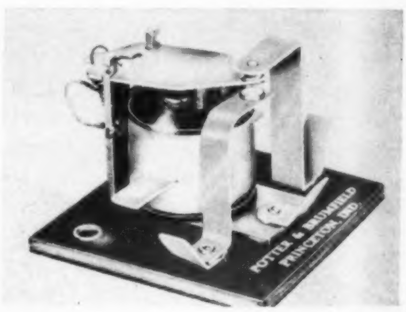
New Parts

Packless valves have fluid-contacting parts of brass or stainless steel for corrosion resistance. They can be mounted in any position. Either class A or H coils are available. Currently available are 3/8 and 1/2-in pipe sizes. Made by **Automatic Switch Co.**, 391 Lakeside Ave., Orange, N. J.

For more data circle MD-81, Page 297

Appliance Relay

Series MW relay, designed primarily for household appliances, is available with varnish-impregnated ac or dc, current or voltage-actuated coils. Large silver contacts afford substantial wiping action and

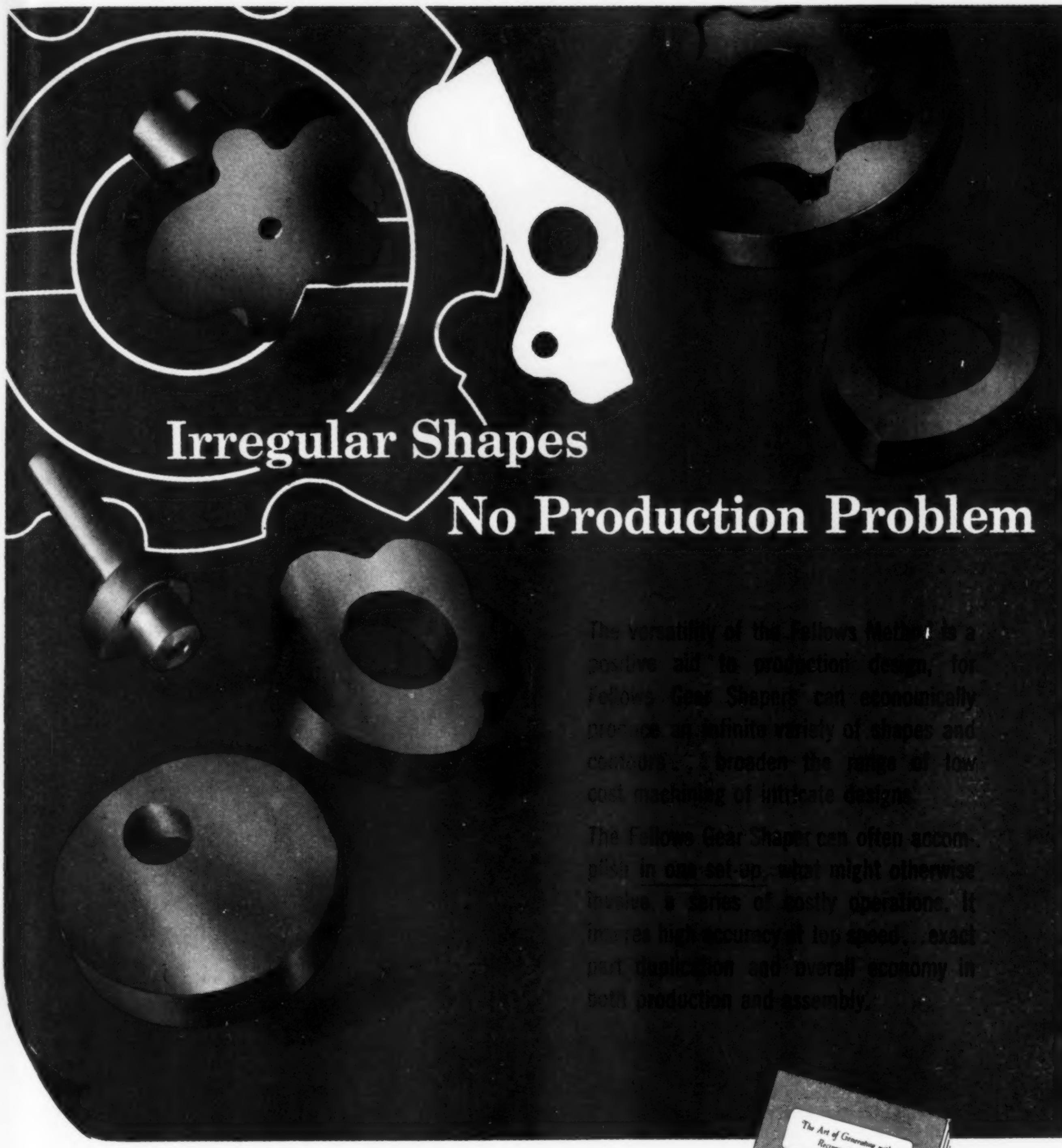


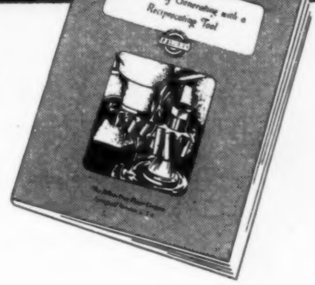
are rated 5 amp or 3/4-hp, 115-v, ac noninductive load. Heavy copper shading ring prevents chatter and hum. Insulation withstands 1500 v rms breakdown. Mounted on laminated Bakelite base, relay uses clip-on solder or screw terminals and mounts with rivets or screws. It is 2 x 2 x 1 1/2 in. high. Made by **Potter & Brumfield**, Princeton, Ind.

For more data circle MD-82, Page 297

Small Gearmotors

Fractional-horsepower gearmotors in both right-angle and concentric-shaft designs are 10 per cent lighter than previous models. Driving motor is close-coupled and positively geared to output shaft for maximum torque transmission, uniform speed and no slippage. Motors are reconnectable externally to reverse direction of shaft rotation. Both models are available in ratings of 1/4, 1/3, 1/2 and 3/4-hp





How the Fellows Method can be economically utilized for the production of many different shapes and parts is explained in "The Art of Generating with a Reciprocating Tool". A copy is yours for the asking!

THE Fellows GEAR SHAPER COMPANY

Head Office and Export Department: 78 River Street, Springfield, Vermont.

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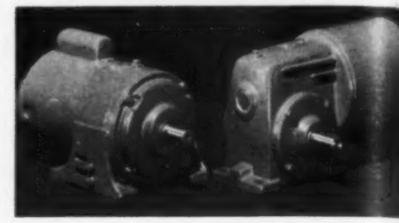


and operate on 115/230 v single-phase and 220/440 v three-phase current. Concentric-shaft units range in output speed from 13.5 to 520 rpm, while right-angle shaft models range from 24 to 148 rpm. Made by **General Electric Co.,** Schenectady 5, N. Y.

For more data circle MD-83, Page 297

Flange Nuts

Gripco locknuts are now available in flange style in sizes from $\frac{1}{4}$ through $\frac{5}{8}$-in. with either NF or NC threads. Both self-locking and standard types are included in this line. A typical application for

the one-piece combination nut and washer is as compressor or motor hold-down nut. Made by **Grip Nut Co.,** 310 S. Michigan Ave., Chicago 4, Ill.

For more data circle MD-84, Page 297

Toggle Switches

Two single-pole, double-throw basic switching units are included in series 11AT toggle switches. One unit is actuated in each extreme toggle position; neither unit is actuated in the center, or neutral, position. Use of the two switching units affords many different circuit combinations, including the making or breaking of circuits in all three toggle lever positions. Six models in the series vary in the combinations of momentary and detented toggle lever positions. Three use standard AN-3234-1 basic switches, and the other three have impact-resistant

BARNES PUMPS TEAM UP WITH DOERR MOTORS

for better design

Constant-Flo motor pumps are smaller, weigh less, eliminate alignment problems.

BEFORE—
Conventional, separate pump and motor mounted on cast base plate.

AFTER—
Constant-Flo motor pump combination results in compact, lightweight unit.

HERE is a new "Pressure Package" made possible through a unique close-coupled construction. This line of rotary gear pumps, manufactured by the John S. Barnes Corporation, Rockford, Illinois, can deliver pressures up to 3000 psi. Motors are available in the NEMA 42, 56 and 66 frames in a range from ⅙ to 1½ hp.

The rapidly growing list of applications already includes automatic door operators, forced lubrication, filters, material stackers and elevators, crimping machines, vegetable dicers, fuel oil transfer, coolant pumps, chair lifts and machine tools.

This is another example of product improvement —the use of Doerr motors provided the manufacturer with the proper engineering features as well as a reliable source of supply. We would be pleased to consult with you on your motor applications.

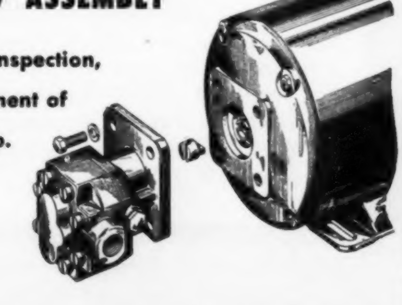
YOU GET MORE WITH DOERR!

DOERR
Electric Corporation
CEDARBURG, WISCONSIN

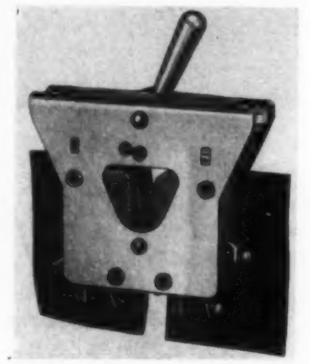
Electric Motors from 1/30 to 5 hp. Standard or Designed to Your Specifications

SIMPLIFIED ASSEMBLY

Permits easy inspection, quick replacement of motor or pump.



high-strength plastic case switching units. These units are Underwriters' Laboratories listed for 10 amp at 125 or 250 v ac, ½-amp

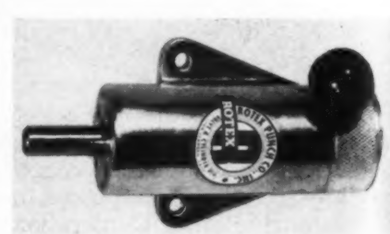


at 125 v dc, ¼-amp at 250 v dc. Made by Micro Switch Div., **Minneapolis-Honeywell Regulator Co.,** Freeport, Ill.

For more data circle MD-85, Page 297

Miniature Air Cylinder

Valve-in-head air cylinder has 1⅛-in. bore and 1-in. stroke. Corrosion-resistant body incorporates a hand lever valve. Cylinder has

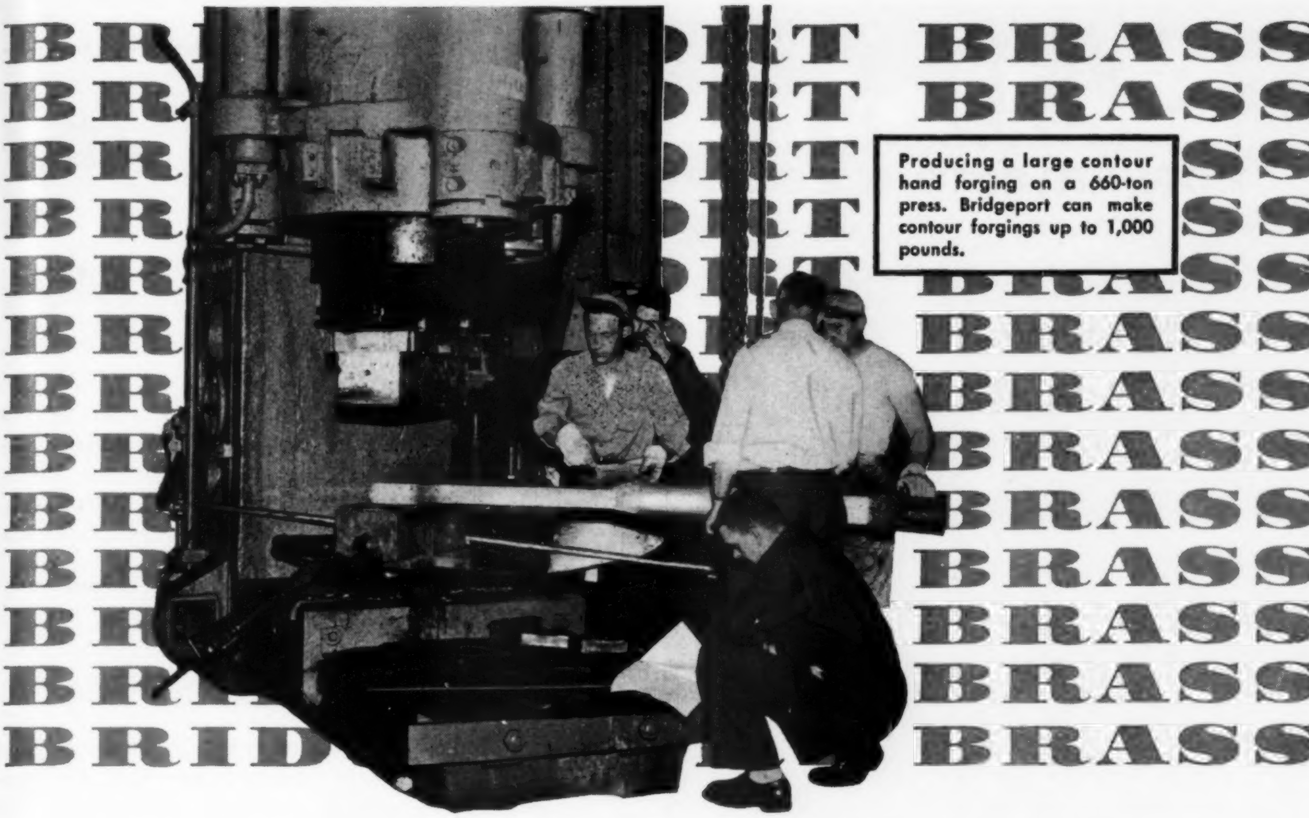


one hose line and may be connected to any air outlet. Maximum operating pressure is 160 psi. Made by **Rotex Punch Co. Inc.,** San Leandro, Calif.

For more data circle MD-86, Page 297

Stainless Steel Fittings

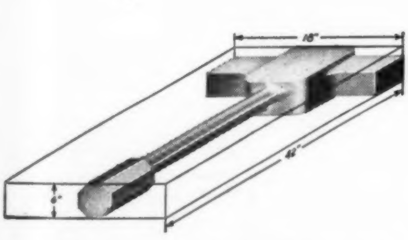
Centrifugal casting method is used to produce high strength stainless steel fittings to standard AN specifications or to special requirements. Under test, fitting did not leak after being subjected to 12,000-psi hydraulic pressure for 8 hours, as well as increased



Producing a large contour hand forging on a 660-ton press. Bridgeport can make contour forgings up to 1,000 pounds.

BRIDGEPORT CONTOUR HAND FORGINGS

—for lighter, stronger parts at lower cost



See how much metal and machining are saved by using a contour hand forging instead of a solid slab from which a machined part would be made. The physical properties of the forging are far superior, too.

Bridgeport's Forging Folder describes the advantages of forgings in many applications. Write or call for your copy.

Aluminum and magnesium contour hand forgings offer a number of savings in terms of die costs, time and materials over other methods of producing a limited number of units—especially for experimental and prototype use.

Bridgeport Contour Hand Forgings have these advantages:

1. Save metal and reduce machining.
2. Grain in forged metal more closely follows contour of part, giving more strength.
3. Furnished in T-6 condition, in most cases ready for machining.
4. X-ray, zyglo and ultrasonic testing of every forging assures highest quality.
5. Inventory of aluminum or magnesium forging alloys available for fast production.

Bridgeport's skilled know-how and modern forging facilities with press sizes up to 16,500 tons also assure quality die forgings. For prompt, dependable service on all types of forgings, call your nearest Bridgeport Sales Office.

BRIDGEPORT BRASS COMPANY

ALUMINUM DIVISION—BRIDGEPORT 2, CONNECTICUT

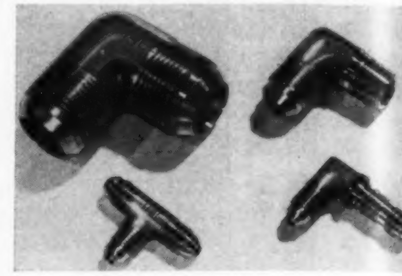
Sales Offices in Principal Cities—Conveniently Located Warehouses

Mills at Bridgeport, Conn., Indianapolis, Ind., and Adrian, Mich.

Bridgeport Brass Co.

BRIDGEPORT ALUMINUM

New Parts



pressures to 22,500. Fittings of many sizes and shapes are available in various stainless alloys. Made by **Industrial Research Laboratories,** 961 E. Slauson Ave., Los Angeles, Calif.

For more data circle MD-87, Page 297

Circuit Breakers, Switches

Line of circuit breakers and motor starting switches for hazardous locations is designed for Class I, groups C and D (NEMA type VII); Class II, groups E, F and G; and Class III (NEMA type IX and V). Explosionproof and

dust-tight units have ferrous alloy bodies and aluminum alloy covers. They are available in single or two-gang types with dead-end or through-feed hub arrangement in ½, ¾ and 1-in. sizes. Circuit breaker ratings are up to 30 amp, 120 v ac, while motor starters are made in ratings up to 1 hp. Manual motor starting switches are available with or without overload protection and interchangeable heater units. Made

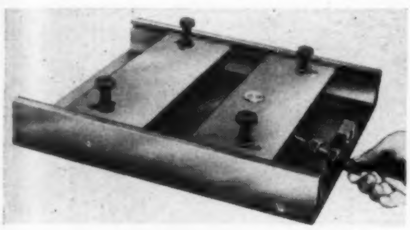
(*Continued on Page* 319)

(Continued from Page 314)

by **Pyle-National Co.**, 1334 N. Kostner Ave., Chicago 51, Ill.
For more data circle MD-88, Page 297

Motor Base

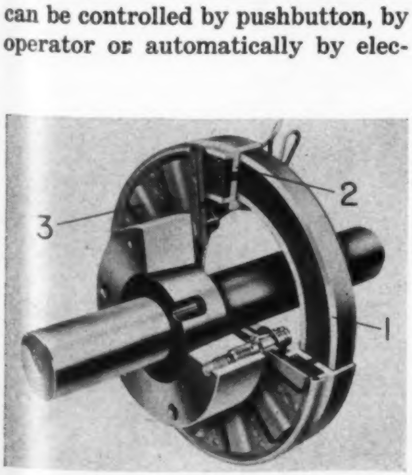
Release of adjusting screw in Quick-Slide motor base permits moving the motor after the base is bolted down. Easy adjustment of



center distances is thus provided for variable-speed drives. Made by **T. B. Wood's Sons Co.**, Chambersburg, Pa.
For more data circle MD-89, Page 297

Electric Brakes, Clutches

Electric brakes and clutches in the torque range of 8 lb-in. to 700 lb-ft may be used for synchronizing machine motion, controlling indexing and positioning, interlocking or simplifying automation. Compact brake is comprised of field (1), replaceable facing (2), and armature (3). Wear adjustment is automatic. Companion electric clutch operates on stationary field principle in which current is induced into rotating coil, eliminating slip rings or brushes. Both brake and clutch can be controlled by pushbutton, by operator or automatically by elec-

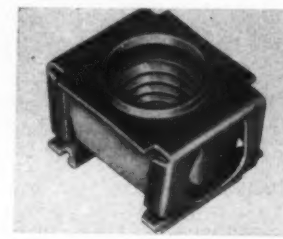


tric switches, relays or electric eyes. Made by **Warner Electric Brake & Clutch Co.**, Dept. PR, Beloit, Wis.

For more data circle MD-90, Page 297

Self-Anchoring Nut

A simple hand tool locks the self-anchoring Speed Grip fastener in a panel hole ready to receive the screw. T-shaped fastener is preassembled in spring steel retain-

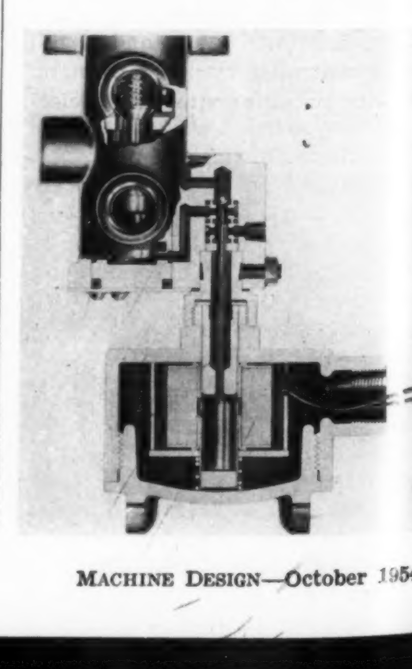


ing cage which prevents rotation after installation. Fastener is designed to withstand large amounts of torque and is suitable for applications where such handling techniques as stacking and butting are used. It can be attached after finishing processes, eliminating retapping or masking operations. Made by **Tinnerman Products Inc.**, P. O. Box 6688, Cleveland 1, O.

For more data circle MD-91, Page 297

Solenoid Air Valves

Extremely short solenoid stroke combined with pilot operation elim-

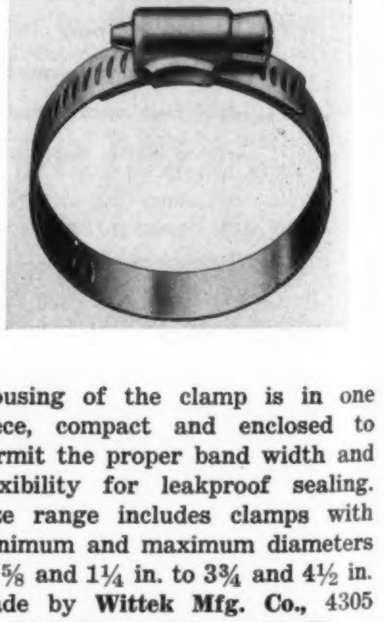


inates coil burn-out in new explosion-proof valves. Poppet design with linear sealing contact on resilient seats makes both pilot and main valve self-cleaning. Removable cover provides quick access to the solenoid. Coils are interchangeable, permitting conversion to any standard voltage by a simple coil change. Made by **Barksdale Valves,** 5125 Alcoa Ave., Los Angeles 58, Calif.

For more data circle MD-92, Page 297

Stainless Steel Hose Clamp

Sure-Tite clamp with worm drive fastener is detachable and can be applied quickly to hose which is already in position. No special tools are required for installation. The one-piece hardened screw is deep slotted and will accommodate any size screwdriver.



Housing of the clamp is in one piece, compact and enclosed to permit the proper band width and flexibility for leakproof sealing. Size range includes clamps with minimum and maximum diameters of 5/8 and 1¼ in. to 3¾ and 4½ in. Made by **Wittek Mfg. Co.,** 4305 W. 24th Place, Chicago 23, Ill.

For more data circle MD-93, Page 297

DC Solenoids

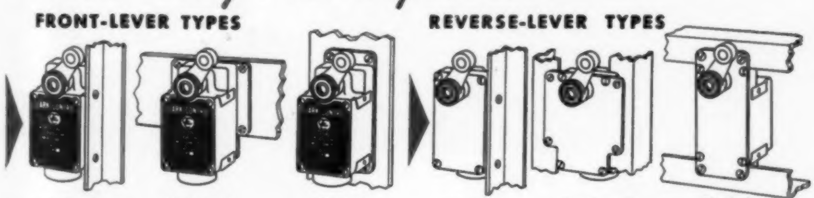
Twenty standard parts can be combined to form 300 different types of miniature dc solenoids in 100 and 300 series. Lightweight and compact, solenoids provide high power. A wide variety of mountings, coil sizes and wire sizes is available, and the units can be

NEW!

CLARK *Type DM* MACHINE LIMIT SWITCH

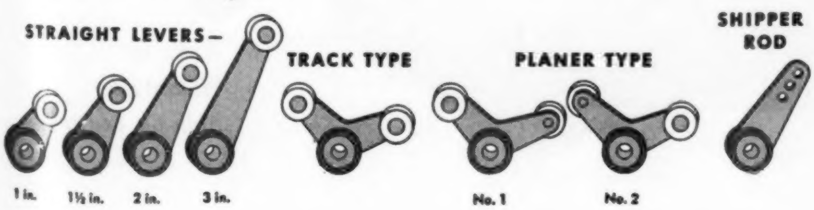
• This new heavy-duty limit switch is built with a minimum of moving parts, and with emphasis on simplicity of construction. The primary objective in its design is to provide dependable, accurate, trouble-free operation for a long life. All latch and trip-bearing surfaces are nylon to steel for minimum wear. All springs are in compression for greatest safety—they cannot be overloaded. This and other features make the switch as nearly fail-safe as possible.

Mounting Arrangements



Side Mounted · Horizontal Flange Plate · Vertical Flange Plate · Side Mounted · Horizontal Flange Plate · Vertical Flange Plate

Operating Levers



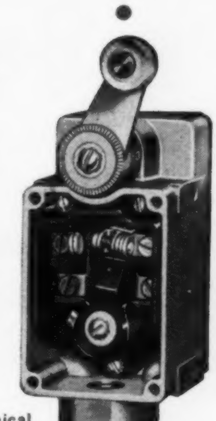
1 in. · 1½ in. · 2 in. · 3 in. · No. 1 · No. 2

Nylon roller cushions impact, has low friction coefficient and long wearing qualities.

Reversible operating lever. Simple screw driver adjustment for reversing or positioning.

Heavy molded insulating chamber surrounds all live parts and provides ample wiring space for four No. 12 wires with Stakon connectors.

Areas subjected to arcing are protected by glass-melamine plates.



Electrical and mechanical sides of switch are completely isolated.

Nema Type 5 dust-tight, oil-tight enclosure of heavy die-cast construction.

Double-concentric overtravel springs in compression for fail-safe operation.

Return spring is in compression. Can be changed without tools to either side of arm, or removed for maintained contact.

Spring-loaded latches are nylon for low friction and long life.

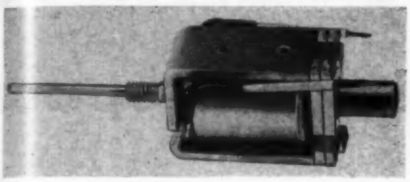
Choice of ½" or ¾" conduit opening.

Write for Bulletin 102DM

The CLARK CONTROLLER Company

Engineered Electrical Control

1146 East 152nd Street • • Cleveland 10, Ohio



changed to push or pull type by addition of a threaded push rod to any plunger. Typical solenoids in AWG-S.F. wire sizes 30 through 44 have resistances ranging from 14 through 13,200 ohms. Made by **Joseph Pollack Corp.**, 81 Freeport St., Boston 22, Mass.

For more data circle MD-94, Page 297

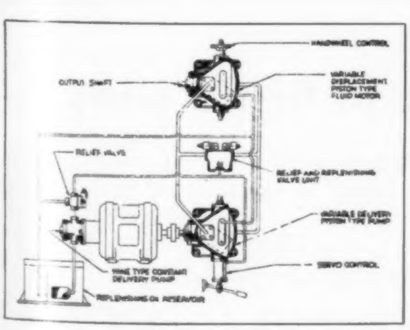
Industrial O-Rings

Precision molded from Buna N fuel and oil-resistant compounds, series of industrial O-rings is suitable for both hydraulic and pneumatic service. Rings are available in all standard sizes from 1/4 to 16 in. OD; other sizes can be made to specifications. Made by **Stillman Rubber Co.**, 5811 Marilyn Ave., Culver City, Calif.

For more data circle MD-95, Page 297

Split Hydraulic Transmission

Completely sealed and self-lubricated drive consists of pump, motor and appropriate valving combined to provide a positive displacement type fluid power transmission having infinitely variable

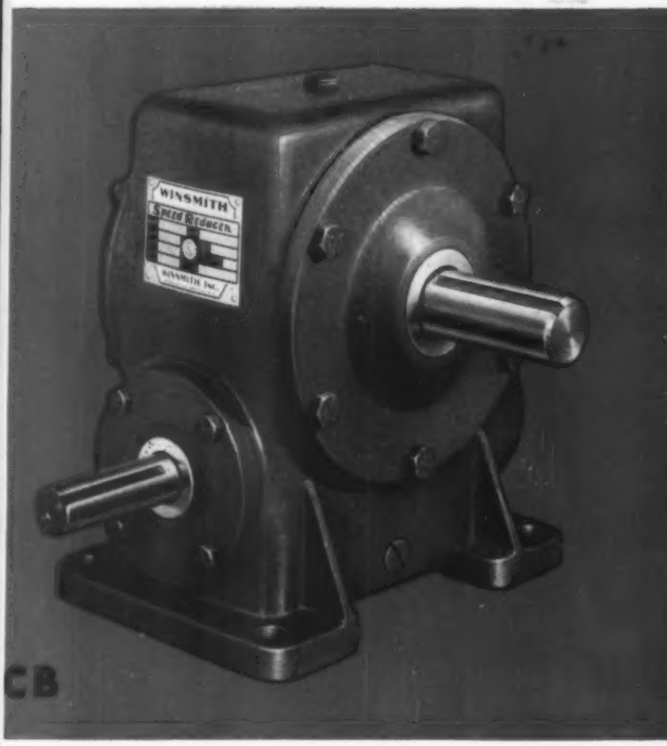


speed control. Both the pump and the hydraulic motor have controls for regulation of output speed and power. Acceleration and deceleration rates are independently adjustable. Pump and motor can

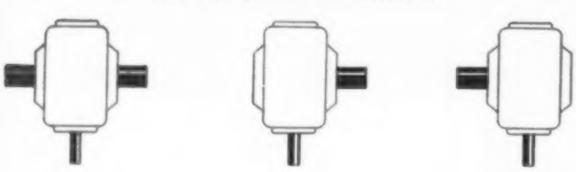
(*Continued on Page* 328)

THE *ALL-NEW* "C" LINE . . .

provides greater capacity in less space. . .



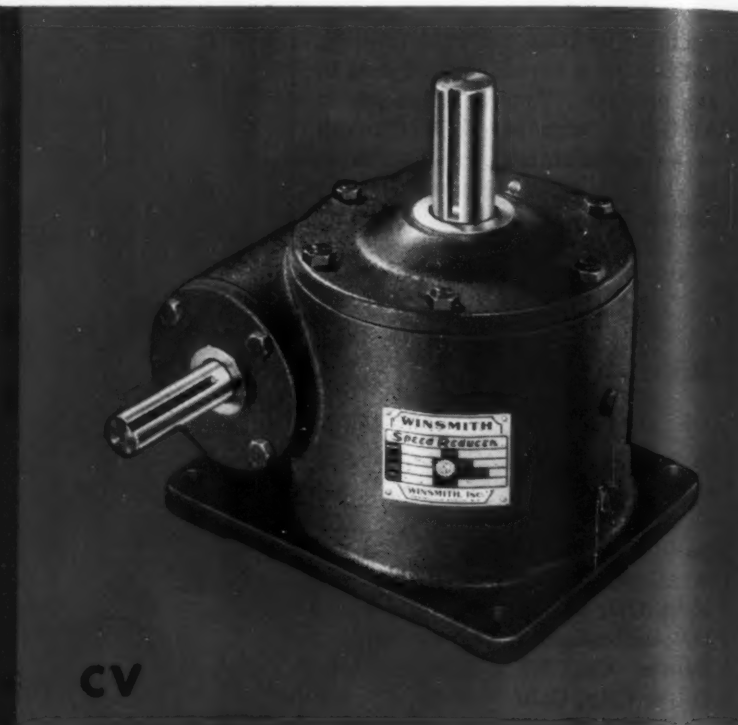
SHAFT ARRANGEMENTS



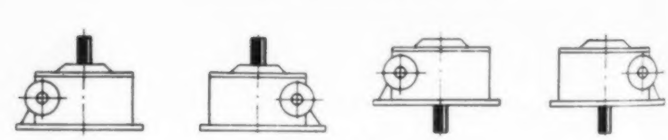
STANDARD ASSEMBLY I-LR

SPECIAL ASSEMBLY I-R

SPECIAL ASSEMBLY I-L



SHAFT ARRANGEMENTS



STANDARD ASSEMBLY I-RU

SPECIAL ASSEMBLY I-LU

SPECIAL ASSEMBLY I-RD

SPECIAL ASSEMBLY I-LD

3 NEW DESIGNS each now available in first 5 sizes

TOP RATED HORSEPOWER AND TORQUE OUTPUT

Both input and output shaft diameters are increased in size to handle greater loads. All units are equipped with gears, bearings and shafts rated for AGMA Class 1 Service.

INCREASED OVERHUNG LOAD CAPACITY

Larger input and output shafts plus larger and stronger bearings also provide a greater chain pull capacity.

EXTRA RUGGEDNESS FOR LONG SERVICE

Special nickel phosphor bronze, used exclusively in Winsmith Worm Gear Speed Reducers, has 100% greater nickel content than bronzes commonly used for gears. It has the greatest strength of all the phosphor bronzes.

STURDY, ONE-PIECE HOUSINGS

Housings are of sturdy, one-piece construction rigidly reinforced to provide secure mounting — hence, smooth, vibrationless operation.

COMPACT SPACE-SAVING CONSTRUCTION

Greater economy per horsepower dollar is afforded. Installation, as well as space problems in machine design, are simplified.

New Parts

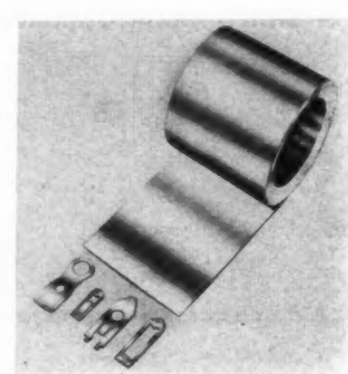
(*Continued from Page 325*)

be separated to meet space limitations or facilitate alignment and can be used where drive requirements demand special combinations of a pump and more than one hydraulic motor. Piston pumps for use with split transmissions are available in input ratings from 0.20 to 36.5 hp, delivering up to 58 gpm. Hydraulic piston type motors are available for output requirements from 3 to 25 hp. Duty can be continuous, intermittent or continuous reversing without shock. Made by **Vickers Inc.,** 1400 Oakman Blvd., Detroit 32, Mich.

For more data circle MD-96, Page 297

Beryllium Copper Strip

Thicknesses from 0.001 to 0.025-in. are available in Penntemp mill hardened or pretempered beryllium copper. Strip has minimum tolerances ranging from ±0.0001 to ±0.0004-in., depending upon thickness. It offers many features of age-hardening beryllium copper, yet requires no heat treatment.



Material has high strength and hardness, good conductivity and fatigue and corrosion resistance. It is available in five tempers, each with a different combination of strength and formability. Made by **Penn Precision Products Inc.,** 501 Crescent Ave., Reading, Pa.

For more data circle MD-97, Page 29?

Miniature Lubricator

Consisting of reservoir, filter pump and metering units, L Special automatic miniature lubrica-

tion system is designed for small machine elements. It measures $2\frac{1}{4}$-in. high, $1\frac{3}{8}$-in. deep and $1\frac{1}{2}$-in. wide. Reservoir holds 20 cc, and pump can be adjusted to discharge a total of 0.6, 0.45 or 0.3-cc each time plunger is pulled. Lubricator can be installed to discharge into passages drilled into the machine and proportion lubricant into

various passages in varying amounts, or it can discharge into tubing leading to these points. Up to four metering units can be installed inside one lubricator. Metering units can also be installed either at tubing junctions or lubrication points. Lubricator has a $\frac{5}{8}$-in. window to indicate reservoir oil level. Made by **Bijur Lubricating Co.,** 151 W. Passaic St., Rochelle Park, N. J.

For more data circle MD-98, Page 297

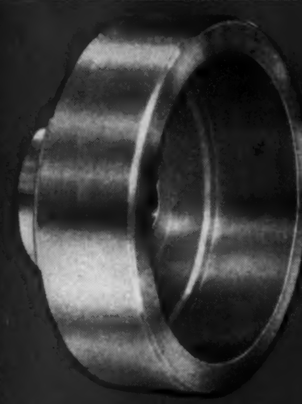
Check Valve

Maximum flow with low opening pressures and leak-proof operation are provided throughout working range of Warren check valve. Consisting of only a two-piece metal body and a replaceable composition sleeve, the valve has neither seat, spring nor other metal moving

THE *New* HILLIARD

TWIFLEX

AUTOMATIC CENTRIFUGAL CLUTCH COUPLING *with* *Flexible* ACTION . . .



11 NEW IMPORTANT FEATURES . . .

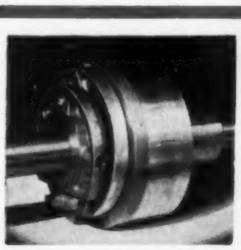
1. Flexible in all directions.
2. Absorbs shock.
3. Limits torsional vibration.
4. Has adjustable idle speed.
5. Can be furnished in automatic free-wheeling type.
6. Smooth starting.
7. No slip under normal load at full speed.
8. Protects driver and driven mechanisms against overload shock.
9. Can be furnished in automatic back-stop type.
10. Prevents torsional resonance.
11. Easily assembled even in blind installations.

If you have problems of misalignment — smooth starting — vibration — overload — or assembly in the manufacture or operation of:

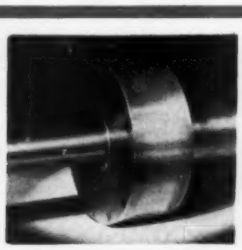
COMPRESSORS
BLOWERS
DIESEL ENGINES
EXCAVATORS
REFRIGERATION EQUIPMENT
• TEXTILE MACHINERY
• WIRE DRAWING MACHINES
• FANS
• GASOLINE ENGINES
• BACK STOP BRAKES
• CONVEYORS
• BALL MILLS
• ELECTRIC MOTORS
• GENERATORS
• HIGH SPEED PULVERIZERS
• LARGE OVERHEAD CRANES
• HAMMER MILLS
• MIXERS
• TUBE MILLS
• PUMPS

• LET OUR ENGINEERS CONSIDER YOUR PROBLEMS. TWIFLEX MAY BE THE ANSWER.

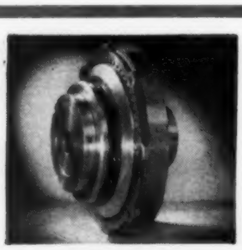
THE HILLIARD LINE OF CLUTCHES •



Single Revolution Clutch
Write for Bul. 239



Over-Running Clutch
Write for Bul. 231



Slip Clutch
Write for Bul. 300

• WRITE TODAY!
for details of TWIFLEX Coupling in Catalog CE-3
•

THE HILLIARD *Corporation* 103 W. FOURTH ST., ELMIRA, N. Y.

• MANUFACTURING CLUTCHES FOR OVER 45 YEARS •

parts. Valve can be mounted in any position. It operates silently, resists vibration and remains tight in the presence of small amounts of foreign matter. Made by **Betts Machine Co.**, 1800 Pennsylvania Ave. W., Warren, Pa.

For more data circle MD-99, Page 297

Miniature Relays

Miniature TS telephone type direct current relay is available with coils for standard voltages up to 125 v dc or resistances up to 6500 ohms. Ambient temperature range is —55 to 85 C, and special coils are obtainable for -65 to 125 C. Relay withstands shock and acceleration up to 50 *g* and vibration up to 10 *g* at 5 to 500 cycles per second, depending on contact

sizes and combinations which can be up to 6-pole, single-throw in open type and 4-pole, double-throw in closed type. Standard fine silver contacts are rated 3 amp at 28 v dc, 1 amp at 115 v ac, noninductive. Unit has 1-million cycle life expectancy and is 1000-v rms insulated. It is available varnish-impregnated and can be hermetically sealed. Made by **Comar Electric Co.**, 3349 Addison St., Chicago 18, Ill.

For more data circle MD-100, Page 297

Titanium-Base Alloy

High-strength A-110AT titanium-base alloy sheet contains 5 per cent aluminum and 2½ per cent tin. The alloy is readily weldable with the same techniques used for commercially pure titanium and the

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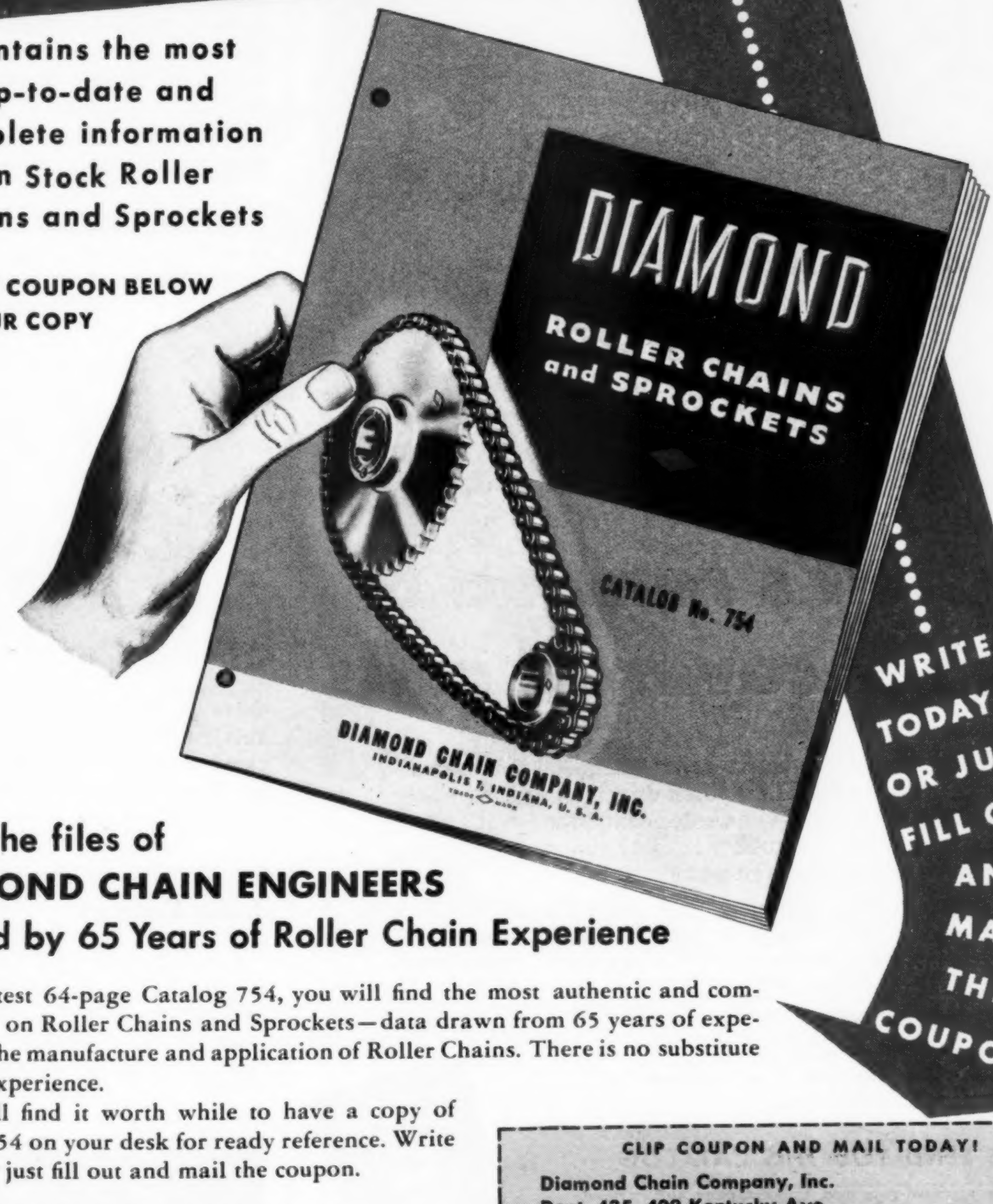

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New Parts

ductility of fusion welded joints is good. Material has minimum tensile strength at room temperature of 115,000 psi and maintains this strength at elevated temperatures. It is supplied in sheet form in thicknesses down to 0.025-in., as well as plates, bars and forging billets. Made by **Rem-Cru Titanium Inc.,** Midland, Pa.

For more data circle MD-101, Page 297

Self-Locking Nuts

Serrated, hardened teeth on the face of these self-locking nuts provide locking action. One-piece fast-

eners are free-running and reusable and are available in all machine screw sizes. Made by **Jacobson Mfg. Co. Inc.,** Kenilworth, N. J.

For more data circle MD-102, Page 297

Speed Reducers

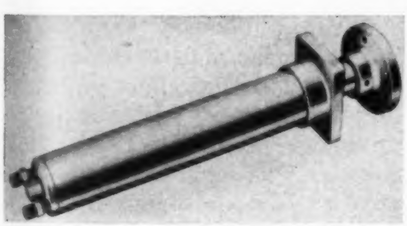
Vertical Shaft-King speed-reduction drives are designed for applications where the driven machine shaft is in a vertical or nearly vertical position. Shaft-mounted

units, which are available in both 13 to 1 and 20 to 1 ratios for requirements through 42 hp, have helical gears; ball and tapered roller bearings; a three-wall, internally ribbed, cast iron housing; large oil reservoir and concentric-shaft design. Units can also be supplied with a torque-arm overload release for protection of the driven machine, motor and drive where jam, choke or shock loads may occur. Made by **American Pulley Co.,** 4200 Wissahickon Ave., Philadelphia 29, Pa.

For more data circle MD-103, Page 297

Air Cylinder

Double-acting, nonrotating shaft air cylinder provides precise registration on each stroke without employing exterior guides. It can be used to position work requiring one or more pressure points which are not on the axis of the cylinder. Location of both ports

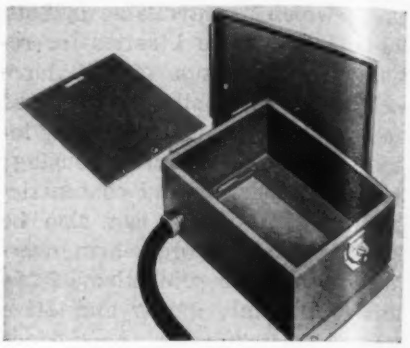


at the rear of the cylinder permits compact installation. Shaft is 7/8 in. in diameter at working end and is available with 4 in. diameter flange, as illustrated, or with clevis. Cylinder is available with 2-in. bore cylinder for 1 to 6-in. strokes or with specified bore and stroke. Made by **Summit Tool & Mfg. Co.,** 2907 Summit St., Toledo, O.

For more data circle MD-104, Page 297

Electrical Wiring Box

Complying with JIC specifications for electrical pull boxes, this enclosure is water, oil and dust-tight. Boxes range in size from 4 x 4 x 3 in. high to 16 x 14 x 6 in. high. Cover has a Neoprene sponge rubber gasket and fastens

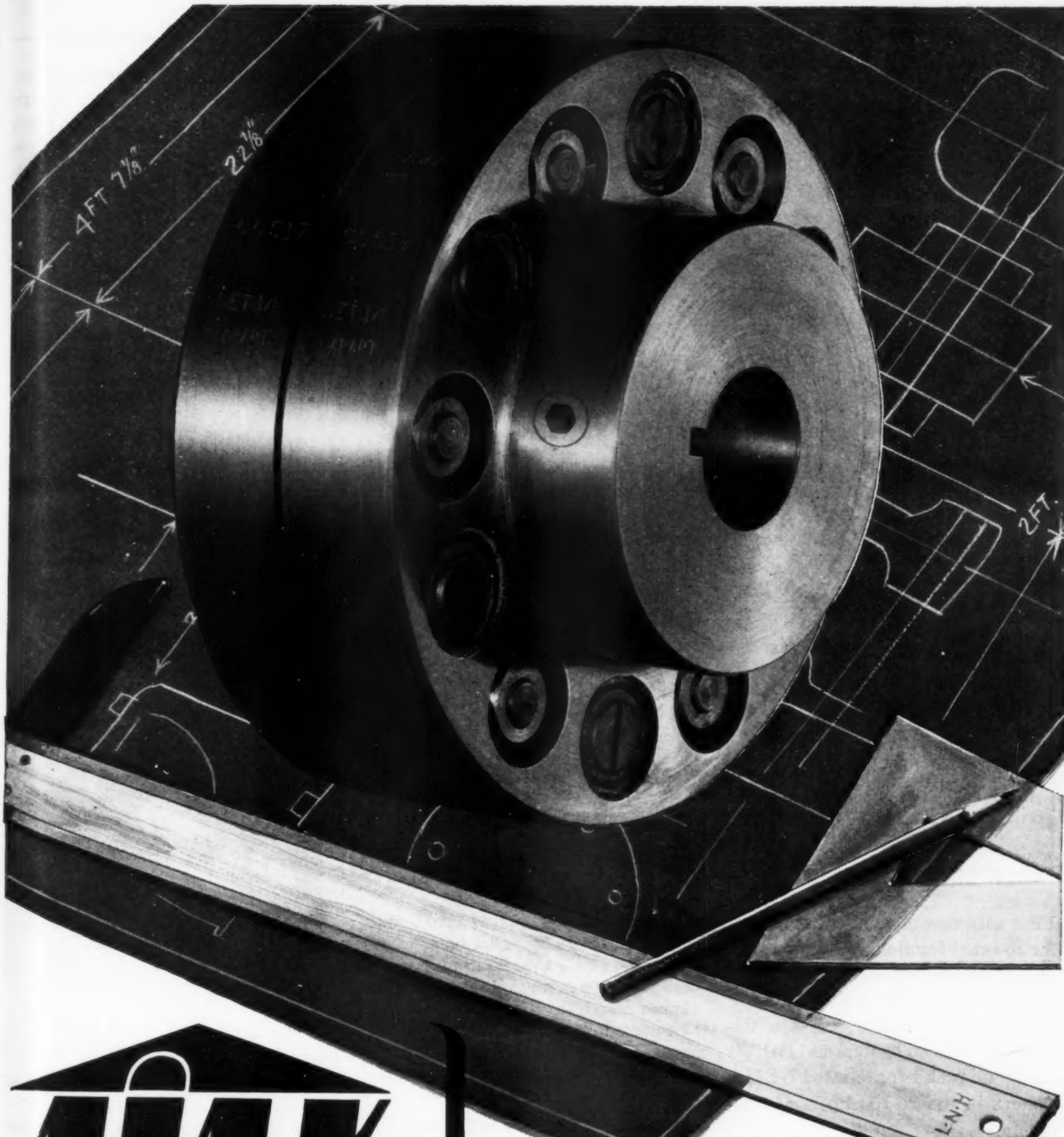


to the box by means of an external hinge and clamp. Made of 14 gage sheet steel, box has mounting feet of 12 gage steel. Removable panel permits mounting of relays, timers and terminal strips. Boxes are normally made without extra holes but can be furnished with knockouts, conduit holes, panel mounting holes and glass windows. Made by **Hoffman Engineering Corp.**, Anoka, Minn.

For more data circle MD-105, Page 297

Variable-Delivery Pumps

One and two-way variable delivery pumps are designed for variable-speed, straight-line and rotary drive applications requiring 1 to 3 hp under precise speed or pressure control. Each pump incorporates a variable-delivery, high pressure, radial piston pump with balanced flat valve; a constant-delivery, low-pressure gear pump; one of eight standard controls; a three-way suction and return valve for differential systems; dual disk type check valves for nondifferential systems; a double-acting high pressure relief valve and a gear pump relief valve. Compact handscrew, hydraulic servo motor lever,


2FT.
L·N·H

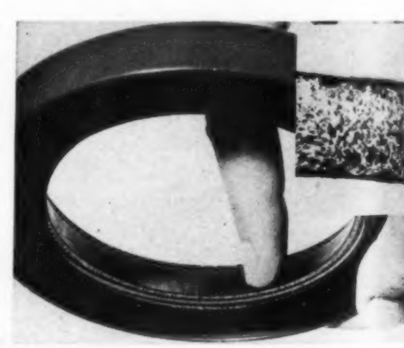
New Parts

automatic adjustable pressure unloading, hydraulic remote, electric remote, electric-hydraulic servo and pneumatic controls mount on either side of the pump case. Drive speed ranges from 710 to 1750 rpm; maximum delivery, from 440 to 1120 cu in. per minute. Maximum continuous working pressure in all pumps is 1140 psi, and peak pressure of 1350 psi can be exerted for short intervals. Made by **Oilgear Co.,** 1568A W. Pierce St., Milwaukee 4, Wis.

For more data circle MD-106, Page 297

Leather Oil Seal

Low-torque operation with no measurable leakage and long life even at 200 F is provided by this Micro-Torc leather oil seal. Unit consists of chrome - retanned leather sealing lip coated with dry lubricant and elastomer material which renders walls of sealing lip

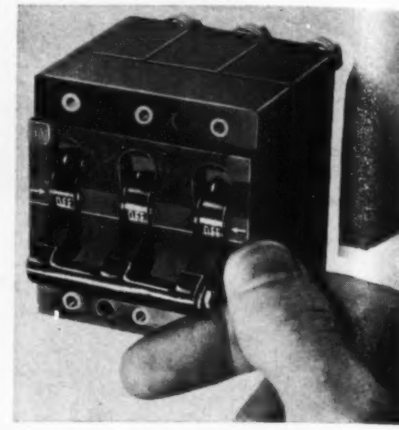


impervious to lubricants. Center portion of sealing member retains natural porosity of leather, allowing it to absorb and store lubricant for use when normal supply is exhausted, making seal practical for starved or semi-starved sealing applications. Made by **National Motor Bearing Co.,** P. O. Box 1030, Redwood City, Calif.

For more data circle MD-107, Page 297

400-Cycle Circuit Breaker

This lightweight 400-cycle circuit breaker for the protection of polyphase circuits is claimed to be the first of its kind. Polyphase operation is accomplished by companion-trip principle, whereby two



or three single-pole circuit breakers in a common assembly are linked together externally at the handles. Tripping out of any one phase causes simultaneous interruption of all phases. Device employs hydraulic-magnetic operation, based solely on current value. Current capacity, minimum and instantaneous trip points are constant, regardless of ambient temperature. No thermal elements are employed. A selection of 400-cycle time-delay response curves is available, as are one, two or three-pole models in any rating from 100 ma to 50 amp. Made by **Heinemann Electric Co.**, 572 Plum St., Trenton 2, N. J.

For more data circle MD-108, Page 297

Precision Cams

Wide variety of types and sizes of cams for most applications includes those for use as highly accurate, compact mechanical memories for analog computers and similar systems. Cams are available complete with followers and all necessary gearing, mounted and ready for incorporation into a sys-

all the world's your stage when you design...

with

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If you're designing with one eye on the export market, Gardner-Denver pumps, air compressors and air motors can help your products earn confidence in any corner of the globe.

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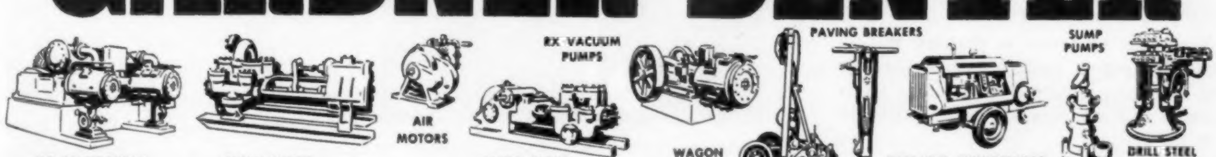


THE QUALITY LEADER IN COMPRESSORS, PUMPS AND ROCK DRILLS FOR CONSTRUCTION, MINING, PETROLEUM AND GENERAL INDUSTRY

Gardner-Denver Company, Quincy, Illinois

In Canada: Gardner-Denver Company (Canada) Ltd., 14 Curity Avenue, Toronto 16, Ontario

New Parts

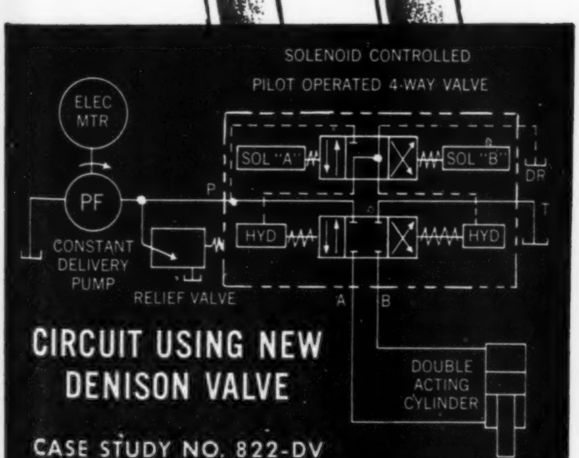
tem, or they can be supplied alone. Cams are classified as three-dimensional or single-input. The former is a compact unit which continuously and accurately satisfies an arbitrary function: $z=f(x, y)$, where x and y are independent variables, and z is the output. Tolerances are as close as ± 0.0005-in., and a wide range of materials is available. Single-input cams include grooved flat cams, external flat cams and grooved cylindrical cams. These designs are most often used to obtain a motion or function which bears a nonlinear relation to another single motion or function: $y = f(x)$. Squares, trigonometric functions, logs, ballistic data and reciprocals of square roots are typical outputs. Made by Ford Instrument Co., Div. of Sperry Corp., 31-10 Thomson Ave., Long Island City 1, N. Y.

For more data circle MD-109, Page 297

Automatic Transmission

Designed for use on two-wheel propelled vehicles such as small tractors and cars, Duo-Drive unit combines functions of clutch, transmission and differential. Belt-drive unit mounts direct on engine crankshaft and consists of two variable-diameter pulleys driving a countershaft for each wheel. Traction wheels are allowed to revolve at different speeds on corners, with full drive to each. Device is controlled by centrifugal governors and is fully automatic. Below factory-set engagement speed, belts are completely released. Drive is a single rotating unit and can be quickly installed on a $1\frac{1}{2}$-in. or longer horizontal shaft. It is available for A or B

Millions of operations without measurable wear



PUMPS
MOTORS
CONTROLS
PRESSES

NEW DENISON ¾" Solenoid Controlled—Pilot Operated Subplate Type 4-Way Valve for operating pressures up to 3000 psi

4 SPOOL TYPES—Provide all positioning arrangements required by most circuits.

SPOOLS POSITIONED 3 WAYS—With solenoid de-energized, spools may be spring offset, spring centered or without springs.

ADJUSTABLE PILOT CHOKES—Available if required for precise control of pilot flow to insure smooth, shockless reversal, time delay or sequence control.

PILOT PRESSURES TO 3000 PSI—Operated with pilot pressures from 50 psi to 3000 psi internally or externally without need for differential pistons.

INTERNAL OR EXTERNAL PILOT PRESSURE—May be internally or externally pilot operated and changed from one to the other in less than 2 minutes.

These SUPERIOR FEATURES in a valve likely INTERCHANGEABLE with that you are now using . . . but at a LOWER COST.

Inquire about quantity discounts.

GET FULL FACTS. Specifications and description are in Bulletins VD-7 and VD-8.

THE DENISON ENGINEERING COMPANY
1240 Dublin Road • Columbus 16, Ohio

DENISON TRADE MARK HydrOILics

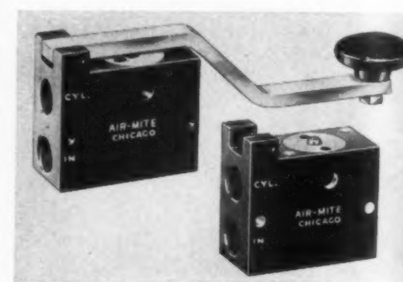
New Parts

belts for ⅝ or ¾-in. shafts and up to 4-hp gasoline engines. Made by V-Plex Clutch Div., **Light Inspection Car Works,** Hagerstown, Ind.

For more data circle MD-110, Page 297

Three-Way Valve

Made with a full ⅜-in. passage, this three-way air control valve is available as a normally-closed model with hand lever or without the lever for machine mounting

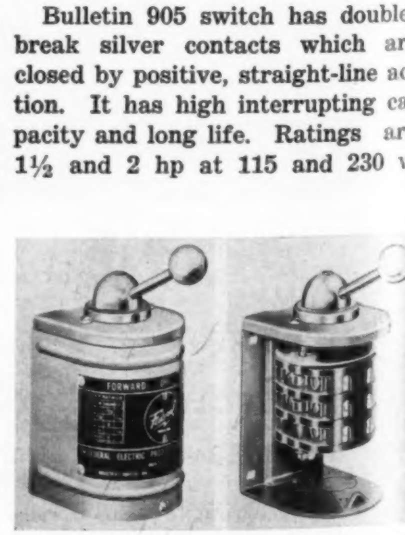


and cam actuation. It operates in any position and instantaneously actuates air cylinders with ⅛-in. movement of plunger. Air connections made to parallel hose nipples at rear keep lines out of the way. Valve is drilled for horizontal or vertical mounting and has brass or aluminum internal components. Dimensions are 2½ x 1¼ x 2⅜ in. without handle. Made by **Air-Mite Devices Inc.,** 4417 W. Carroll Ave., Chicago, Ill.

For more data circle MD-111, Page 297

Reversing Drum Switch

Bulletin 905 switch has double-break silver contacts which are closed by positive, straight-line action. It has high interrupting capacity and long life. Ratings are 1½ and 2 hp at 115 and 230 v,




...solid foundation
FOR TODAY'S
COMPACT
MOTOR DESIGN
There are, as you know, new NEMA Standards for electric motors ... more power in less space.
When you look for a new NEMA frame motor, look for the one that is built on a solid foundation ... it carries the Fairbanks-Morse Seal of Quality.
The Standards are new .. But the Idea Is Not
Like the recent Fairbanks-Morse developments in other lines, the new F-M motor is the result of a basic engineering philosophy: More Performance in Less Space—a 120-year tradition at Fairbanks-Morse. Fairbanks, Morse & Co., 600 South Michigan Avenue, Chicago 5, Illinois
F M
FAIRBANKS-MORSE
a name worth remembering when you want the best
ELECTRIC MOTORS AND GENERATORS • DIESEL LOCOMOTIVES AND ENGINES • PUMPS • SCALES • RAIL CARS • HOME WATER SERVICE EQUIPMENT • FARM MACHINERY • MAGNETOS
NEW MOTOR DESIGN
NEW DIESEL DESIGN
NEW PUMP DESIGN
NEW
NEW SCALE DESIGN
NEW GENERATOR DESIGN
MOTIVE DESIGN
DESIGN

(Advertisement)

Advantages of Worm Gearing

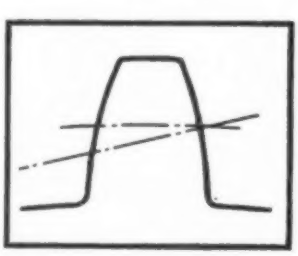
By J. E. Gutzwiller

Assistant Chief Engineer, Worm Gearing Department

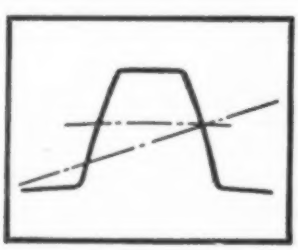
De Laval Steam Turbine Company

Interchangeability—The De Laval Steam Turbine Company was one of the first, if not the very first, manufacturer of heavy duty machinery to build worm gearing with interchangeable parts manufactured under limit gage control. Thus, worm and gear sets of like center distances but of different ratios can be readily interchanged if revision of speeds becomes necessary. Standard parts are always available for maintenance.

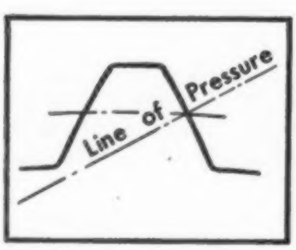
High Shock Load Capacity—The worm gear tooth form is such that the gear teeth are under a crushing, rather than a bending load. For this reason extremely high momentary and shock loads, damaging to many forms of gearing, can be successfully withstood. High momentary overloads seldom cause failure, as worm gear ratings are figured on the wear resistance of the gear teeth.



Standard 14½° involute spur gear tooth and old time worm tooth.



20° stub gear tooth.



De Laval Worm Gear Tooth. Note, line of pressure falls inside base of tooth.

Long Life—Bronze gear teeth maintain their correct form due to the regenerating action of the hardened steel worm, which retains its original shape throughout years of wear. A worm gear drive actually improves with service. This fact is peculiar to worm gearing and contributes to its recognized long life.

Smooth, Quiet Power—De Laval worm gearing transmits power by a continuous shockless action. Three or more teeth are in contact at all times, giving an even flow of torque and uniform angular velocity and eliminating vibration, pulsation, chatter and customary gear noises.

Compact Right Angle Drive—The use of worm gearing makes a neat, closely coupled, compact drive, with the motor shaft at right angles to that of the driven machine.

Larger Gear Ratios Simplify Design—Worm gearing offers larger ratios of speed reduction in a single compact set, another space-saving feature for the design engineer. The larger gear ratios obtainable in a single worm and gear set reduce the number of moving parts required.

Safety and Ease of Maintenance—The small number of moving parts in a worm gear drive may be readily enclosed, thus avoiding the hazard of exposed moving parts. Assuming proper lubrication, worm gearing operates with minimum attention, even under the most adverse conditions.

Reference Manual On Worm Gear Sets

Design engineers will find this new catalog a helpful working tool in the selection of worm gear sets. It contains examples of how to select worm gearings, worm and gear data, standard worm mounting dimensions, horsepower ratings, data on shaft stresses as well as other information.

Write on your business letterhead for Catalog 5000 to De Laval Steam Turbine Company, 858 Nottingham Way, Trenton 2, New Jersey.

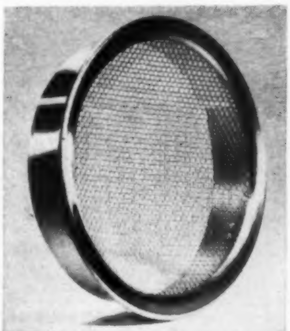
DL 285

single phase ac; $1\frac{1}{2}$ at 110 v and 2 hp at 220 and 440/550 v, two and three-phase ac; and $\frac{1}{4}$-hp at 115 and 230 v dc. Reversible operating handle can be changed to operate from the front, back, or either side of the switch without necessitating removal of the cover. Terminals are easily accessible upon removal of the cover. Holes on bottom and back of switch enclosure permit mounting in various types of locations. Made by **Federal Pacific Electric Co.,** 1429 Park St., Hartford 6, Conn.

For more data circle MD-112, Page 297

Copper Louvers

Corrosion-resistant circular copper louvers prevent moisture and fungus damage by assuring adequate ventilation. Recommended for paint protection, they are also suitable for ventilating instrument and other casings and for



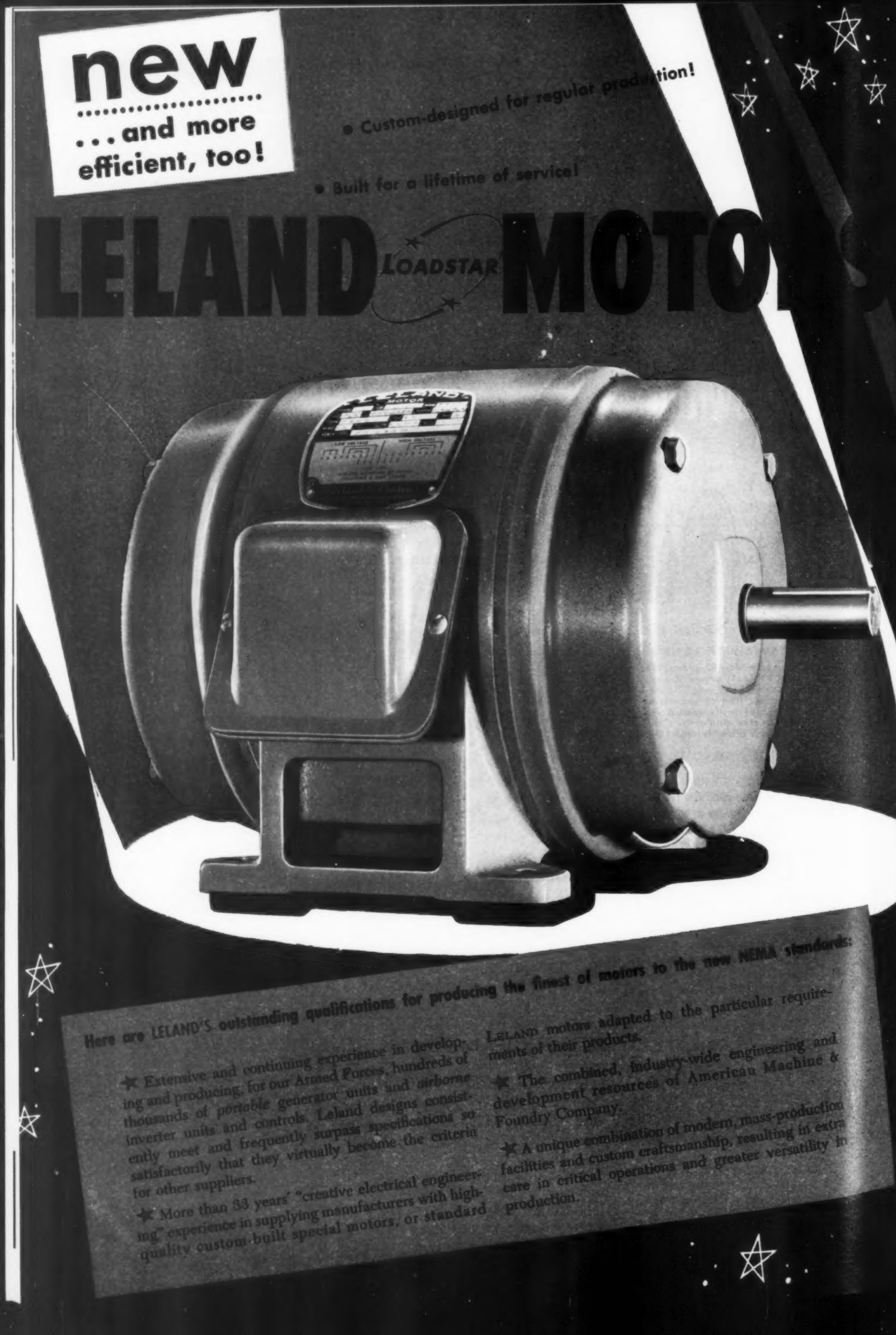
isolating radio frequency interference. Available in weather and termite-resistant design, louvers are made in 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, 4 and 6-in. sizes. Made by **Midget Louver Co.,** 15 Wall St., Norwalk, Conn.

For more data circle MD-113, Page 297

Magnetic Counters

Compact and lightweight, model MC-505AS is a high-speed precision counter which adds and subtracts magnetic pulses in a digital control system. Having five electrically actuated digit wheels, it adds or subtracts from 0000.0 to 9999.9 in response to magnetic

(*Continued on Page* 352)


new
. . . and more efficient, too!
• Custom-designed for regular production!
• Built for a lifetime of service!
LELAND LOADSTAR MOTORS
Here are LELAND'S outstanding qualifications for producing the finest of motors to the new NEMA standards:
★ Extensive and continuing experience in developing and producing, for our Armed Forces, hundreds of thousands of portable generator units and airborne inverter units and controls. Leland designs consistently meet and frequently surpass specifications so satisfactorily that they virtually become the criteria for other suppliers.
★ More than 33 years' "creative electrical engineering" experience in supplying manufacturers with high-quality custom-built special motors, or standard Leland motors adapted to the particular requirements of their products.
★ The combined, industry-wide engineering and development resources of American Machine & Foundry Company.
★ A unique combination of modern, mass-production facilities and custom craftsmanship, resulting in extra care in critical operations and greater versatility in production.

New Parts

(Continued from Page 349)

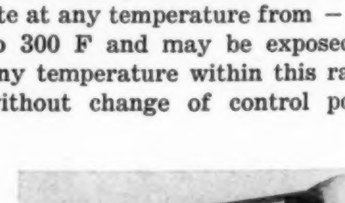
pulses applied to respective terminals. Similar in appearance, model MC-504 SZL is a four-digit, electrically actuated counter that subtracts from 999.9 to 000.0 when

actuated by magnetic pulses and opens or closes a precision snap-action switch at zero level. All wheels of both counters may be set individually to any predetermined number through a sliding front window. Made by **Photocon Research Products,** 421 N. Foothill Blvd., Pasadena 8, Calif.

For more data circle MD-114, Page 297

Adjustable Thermostats

Suitable for direct control of heaters and for temperature alarm or cut-off service, C8 series thermostats are adjustable by means of an arm which projects through the wall of the hermetically sealed space. They can be set to operate at any temperature from − 100 to 300 F and may be exposed to any temperature within this range without change of control point.



These units withstand shock up to 150*g* and vibration of 25*g* at frequencies up to 1000 cycles per second. The encasing shell is the temperature responsive element. Factory settings are ordinarily made to a tolerance of $\pm$ 5 F, and repetitive operation is within $\pm$ 1 F. Differential is about

MAXITORQ
Overload Release
CLUTCH

protects against conveyor overload

FOR THE LAMSON CORPORATION

This prominent Syracuse, N. Y., manufacturer of materials handling equipment has selected the Maxitorq Overload Release Clutch for power transmission on its drive unit for the Lamson overhead conveyor. On installations which handle heavy loads the cam design feature automatically causes instant disengagement of the clutch when the overload is substantially greater than the normal driving load . . . thus preventing damage to product and machine.

The Overload Release Clutch has all of the highly favored features of the standard Maxitorq floating disc clutch . . . Separator springs that keep discs "floating" in neutral . . . no drag, no abrasion and, consequently, no heating in neutral. Assembly, adjustment and take-apart are made without use of tools. Engagement is easily controlled, with light pressure. Disengagement is instant and complete.

There are six capacities, ¼ to 5 h.p. at 100 r.p.m. Maximum working torque from 13 to 263 ft. lbs. There are so many varied applications of this Overload Release Clutch that we suggest submitting your clutch problems to our engineering department for practical recommendations. In other words, "let's talk Maxitorq."

SEND FOR CATALOG NO. MD-10

THE CARLYLE JOHNSON MACHINE COMPANY
MANCHESTER • CONNECTICUT

4 CJ 54

New Parts

1 F. Contact rating is 5 amp at 115 v ac. High potential test is 1250 v ac, and leakage resistance is 500 megohms minimum. Basic thermostat is ½-in. in diameter and 2¾-in. long and weighs 0.04-lb. Forms are available with mounting flanges, mounting brackets, and pipe threaded fittings. Made by **G-V Controls Inc.**, 28 Hollywood Plaza, East Orange, N. J.

For more data circle MD-115, Page 297

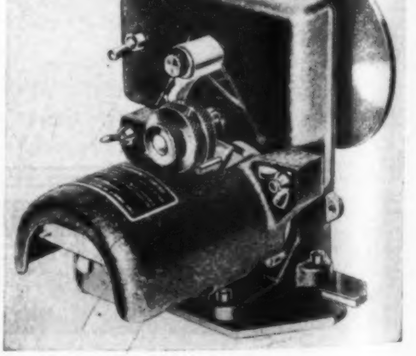
Perforated Sheet

Nonmetallic standard Acouperf sheet materials are available in ten perforation patterns, ten colors, and in flexible or rigid grades from 0.010 to 0.080-in. thick. They are also available with three-dimensional patterned finish. Since materials offer no obstruction to sound passage, they are suitable for use in radio and television sets and for sound reproduction and control. Materials can be stapled, nailed, glued, screwed, cut with shears, knife or scissors or outline diecut. Made by **Pearson Industries**, 4624 N. Sheridan Rd., Chicago 40, Ill.

For more data circle MD-116, Page 297

Range Selector

Developed as an automatic frequency control device, this range selector is adaptable for use with V-belt speed changers or any cam-actuated mechanism requiring variable rotation. It incorporates a camshaft which is turned by a

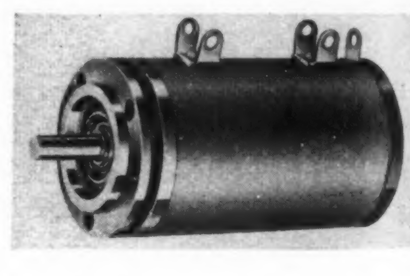


fractional-horsepower speed reduction motor. Shape of cam depends upon requirements. Selector can be set so that cam turns any fraction of a revolution. Two manually adjustable knurled disks on camshaft have stop pins which actuate a limit switch to reverse cam rotation. Device requires space 7 x $8\frac{3}{4}$ x $9\frac{1}{2}$ in. Made by **All American Tool & Mfg. Co.**, 8027 Lawndale Ave., Skokie, Ill.

For more data circle MD-117, Page 297

Miniature Potentiometers

Redesigned series AJ Helipot ten-turn miniaturized precision potentiometers are available in both linear and nonlinear models, for servo or bushing mounting. Unit contains an 18-in. mandrel-wound resistance element which provides resolution as fine as 0.01 per cent.



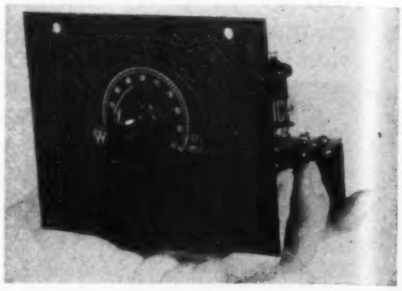
In linear versions standard resistance range is 25 to 100,000 ohms, and standard linearity tolerance is 0.5 per cent. In nonlinear versions, standard conformity tolerance for most functions is ± 1 per cent. Models designated AJSP have servo lid and precision miniature ball bearings; AJS models have servo lid and sleeve bearings; and AJ models have threaded bushing and sleeve bearings. Terminals are gold plated. Power rating is 2 w at 40 C ambient. Units are $1\frac{1}{2}$ in. long and $\frac{7}{8}$-in. in diameter. Made by **Helipot Corp.**, 916 Meridian Ave., South Pasadena, Calif.

For more data circle MD-118, Page 297

Interval Timer

Compact type 12 MC electronic interval timer is suitable for push-button, foot switch or other actuation of controlled interval opera-

New Parts



tion of machines. Cathode tubes provide accurate, continuously adjustable intervals from 0.05 to 7 seconds without warmup. Single-pole double-throw relay has normally-open 10-amp contacts. Timer requires 0.1-w for operation from any 105/125-v 25 to 400-cycle ac source. Model 1, illustrated, is designed for panel mounting; Model 2 is mounted in a lacquered steel box measuring 3 x 4 x 5 in. Made by **G. C. Wilson & Co.,** 1950 Eighth Ave., Huntington, W. Va.

For more data circle MD-119, Page 297

Plastic Foam Material

Upon addition of a catalyst, liquid Eccofoam FP, a foam-in-place plastic material, expands and finally cures to rigid thermosetting unicellular foam. Material can be processed at room temperature and can be foamed to any bulk density from 2 through 26 lb per cu ft. For 10 lb per cu ft material, compressive strength is 340 psi; modulus of elasticity, 11,000 psi; dielectric constant, 1.18; and dissipation factor, 0.0004. Uses include void-filling for lightweight structural reinforcement, core material for double walled glass fiber laminates and embedment of electronic components and circuits. Developed by **Emerson & Cuming Inc.,** 869 Washington St., Canton, Mass.

For more data circle MD-120, Page 297

Miniature Connectors

Series G-20 reverse pin and socket connectors are available with two, three or four contacts. Holes in the molding permit side mounting. Precision machined sockets are

Trim costs with this hook-up for valve-killing corrosive services

To end high valve mortality from most corrosive liquids, and to control fluids that must be kept free from contamination or discoloration, stainless steel is the right metal. But it takes more than metal to make a valve. For dependable performance, you need the two-way hookup — Stainless Steel *and* Jenkins time-proved Valve Engineering.

With the increased demand for processing equipment that resists corrosion, more and more Stainless Steel Valves have been added to the Jenkins line. It now includes types, designs, sizes and alloys to meet practically all industrial needs.

Let the famous Diamond trade-mark be your guide when you choose valves of stainless steel. As on *any* Jenkins Valve, it means *extra value* . . . longer, trouble-free service life.

NEW BOOKLET describes the wide range of types, sizes, pressures, and alloys available in Jenkins Stainless Steel Valves, with diagrams and dimensions. Includes description of alloys, helpful information on selection, and survey forms. Ask for Form 200. Jenkins Bros., 100 Park Ave., New York 17.

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VALVES SINCE 1864 TRADE JENKINS MARK
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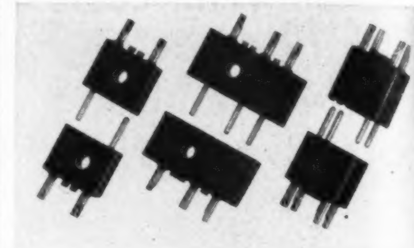
New Parts

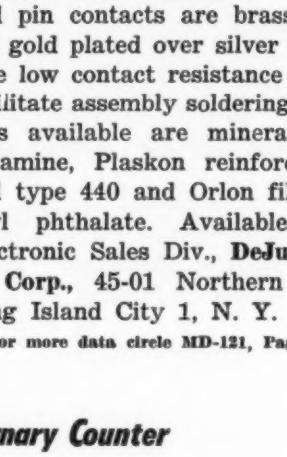


spring temper phosphor bronze, and pin contacts are brass. Both are gold plated over silver to provide low contact resistance and to facilitate assembly soldering. Moldings available are mineral filled melamine, Plaskon reinforced alkyd type 440 and Orlon filled diallyl phthalate. Available from Electronic Sales Div., **DeJur-Amsco Corp.,** 45-01 Northern Blvd., Long Island City 1, N. Y.

For more data circle MD-121, Page 297

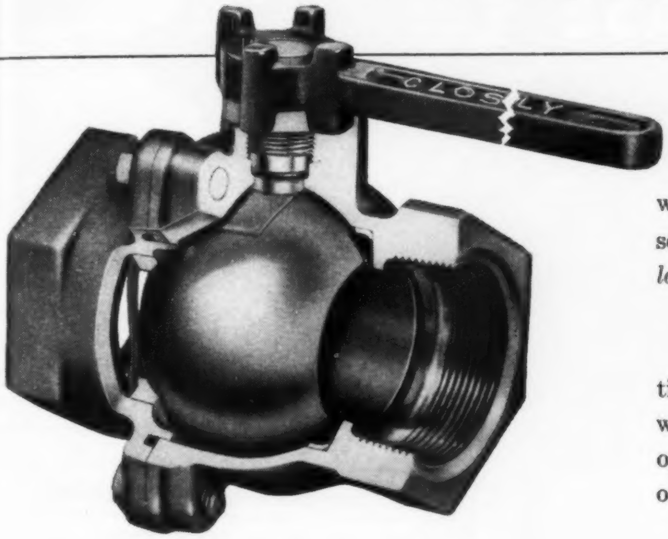
Ternary Counter

Resin-encapsulated plug-in counter has three stable states. Conduction of one tube prevents conduction of two other tubes, so that one of the three outputs is always at a voltage level different from



the level of the other two. Input pulses cause the "odd" output to advance in a sequential manner. Frequently range is 0 to 100 kc. Negative driving pulses with an amplitude between 60 and 150 v and a rise time from 0.5 to 1.5 microseconds are required. Output at any of the three plates is an amplitude of 80 v peak to peak. Output rise time is 0.4 microsec-

Users applaud performance of Rockwood Ball Valves



"Operated 350,000 times with no maintenance."

"The quick turn on and off action and leakproof service of Rockwood Ball Valves enables our furnace operator to properly control process that helps increase furnace capacity."

"Only valves to stay in service over a year."

"Rockwood Ball Valves operate easier and do not bind or stick when opened or closed. Because of their trouble-free service, we have greatly increased our production."

"Definitely superior to any other."

"Unfiltered river water flows through Rockwood Ball Valves in our plant and, under this severe condition, the valves have lasted *4 times longer* than any other make of valve."

"Safest for handling inflammable gases."

"Rockwood Ball Valves are operated 40 times a day, handling a mixture of clay and water. Each valve has performed better, operated easier and lasted longer than any other valve we ever used."

"Real production boosters and cost cutters — *and they need absolutely no maintenance!*" says propane plant supervisor.

"Until we used Rockwood Ball Valves we were replacing or repairing our old valves at least once a week. Rockwood valves have operated 500 times a day without maintenance for over a year."

"Rockwood Ball Valves help keep our syrup processing tanks in operation by giving longer and better trouble-free service. Floors are kept clean, too, because valves close tight and prevent syrup from dripping."

"Out-wear and out-perform all other makes of valves used previously on these installations."

Four exclusive features help give Rockwood Ball Valves their trouble-free efficiency:

Full Round Flow—assures fast operation, less friction loss.

Quick Opening and Closing — valve needs only ¼ turn, even under full pressure.

Longer Wear-Resistance — chrome-plated bronze ball stands up under abrasion, pitting and scratching.

Leakproof — valve stays leakproof in closed position.

Valves come in all pipe sizes. Tested and listed by Underwriters' Laboratories, Inc. Send coupon for complete information.

ROCKWOOD BALL VALVES

FULL, ROUND FLOW

ROCKWOOD SPRINKLER COMPANY
470 Harlow Street
Worcester 5, Mass.

Send me illustrated folder V-4 on Rockwood Full-Flow Ball Valves.

Name.............................

Title.............................

Company.............................

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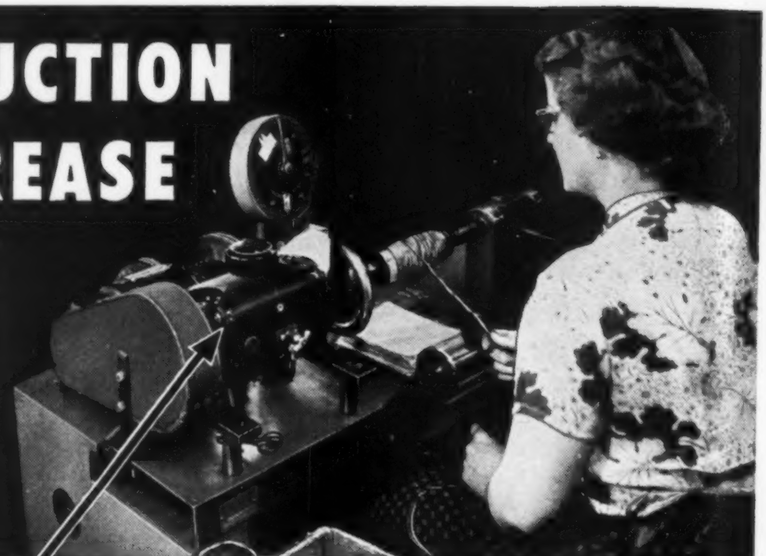
Zone.............. State.....................

18% PRODUCTION INCREASE

Maintenance Practically Eliminated



Winding TV power transformer coils at Sparton Radio-Television

VICKERS®

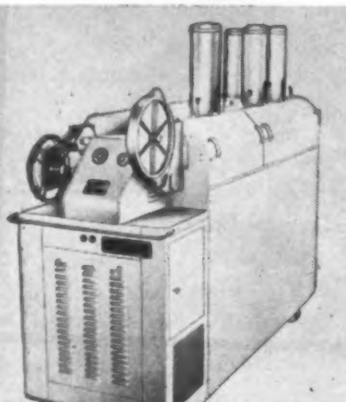
VARIABLE SPEED

Hydraulic Transmission

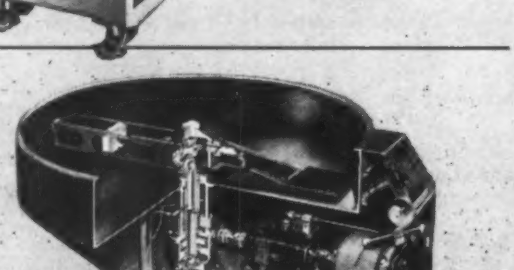
Hourly production was increased 18% when these coil-winding machines at Sparton Radio-Television were equipped with the Series TR3 Vickers Variable Speed Hydraulic Transmission. This improvement resulted from the superior control features inherent in the transmission: (1) extremely quick and smooth variations in speed, (2) maximum torque at low rpm, (3) instantaneous starting and stopping.

While the previous drives required maintenance approximately once a week, the Vickers transmissions have needed attention only three or four times since they were installed four years ago. They have built-in automatic overload protection and they are automatically pressure lubricated by the power-transmitting medium (oil).

Perhaps you have an application where this Vickers Variable Speed Hydraulic Transmission will make similar improvements and economies. Ask the nearest office listed below for Bulletin 47-40a.



Motion Picture Film Processing Machine By Houston Fearless Corp.—Another application where stepless variable speed and constant torque of Vickers Hydraulic Power Transmission provided much more satisfactory operation.



Genisco "G" Accelerator
A rugged, low cost unit used to calibrate accelerometers and other equipment under operational acceleration forces. Speed settings must be accurate and precisely maintained over extended operating periods. Driven by Vickers Variable Speed Hydraulic Transmission.

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1430 OAKMAN BLVD. • DETROIT 32, MICH.

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4486

ENGINEERS AND BUILDERS OF OIL HYDRAULIC EQUIPMENT SINCE 1921

onds. Power consumption is 7 ma at 250 v dc. Counter measures 2 x 2 x 2 in. and weighs 7.5 oz. Made by **Walkirt Co.,** 145 W. Hazel St., Inglewood, Calif.

For more data circle MD-122, Page 297

Miniature Relay

No. 8-4C telephone type relays have low friction loss and withstand extreme vibration at minimum power consumption. Various contact arrangements up to four-pole, double-throw; six-pole, double-throw or 2D (make-before-break) are obtained by combining basic types. Relays are rated at 3 amp

at 32 v dc resistive or at 3 amp at 115 v ac noninductive. Coil rating is 2.8 w nominal; 3.85 w maximum. Relays weigh 2.25 oz; measure 1 7/16 x 1 11/32 x 15/16-in. They are also available hermetically sealed in miniature 9 or 14-pin plug-in or solder terminal types. Made by **Leach Relay Co.,** 5915 Avalon Blvd., Los Angeles 3, Calif.

For more data circle MD-123, Page 297

Adjustable Speed Drives

Fractional-horsepower Adjusto-Spede drives combine ac constant-speed induction motors, eddy-current couplings and electronic speed controls. They are adaptable to business machines, printing and welding machines, wire drawing equipment, conveyors and other diversified applications. Designed for wall, ceiling or floor mounting, drives are available in 1/4, 1/3, 1/2 and 3/4-hp sizes. Electronic speed control insures stability to within

(*Continued on Page* 366)

when you design aluminum parts requiring

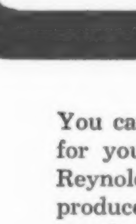
WELDING or BRAZING...

THERE IS NO SUBSTITUTE FOR REYNOLDS EXPERIENCE AND FACILITIES

You can design any welded aluminum parts for your products with confidence because Reynolds Aluminum Fabricating Service can produce these parts and produce them efficiently and economically to your specifications. Reynolds years of day-in, day-out welding and brazing on a wide variety of jobs—plus continuous developments and experimentation in the use of welding and brazing equipment and techniques—assure you the very highest quality welded and brazed parts.

Look at the photos on these pages. Note the variety of Reynolds welding and brazing operations. Reynolds offers welding equipment ranging from 30 to 800 amp., like the automatic fusion welding equipment shown at right capable of continuous welding up to 63 inches per minute and featuring built-in crater fillers that permit crater-free welding. Remember, too, Reynolds constant quality control minimizes "down time"—cuts your costs.

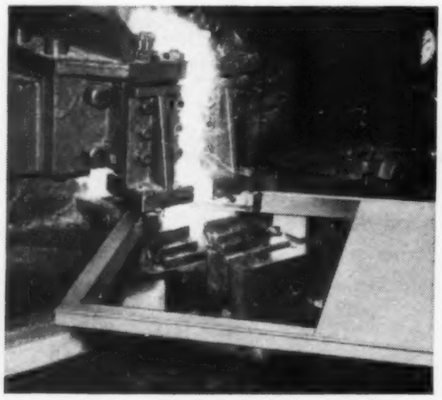
For full details on these operations and on the many other services offered by Reynolds Aluminum Fabricating Service, call your Reynolds office listed under "Aluminum" in your classified telephone directory or write Reynolds Aluminum Fabricating Service, 2061 So. Ninth St., Louisville 1, Kentucky.



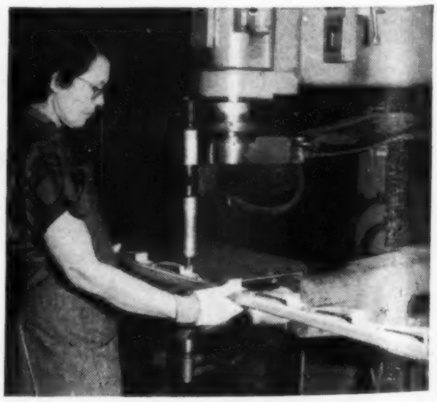
Write for your copy of the new 24-page "Catalog of Facilities." Get full details on the tremendous production facilities of Reynolds Aluminum Fabricating Service.

SEE "Mister Peepers", starring Wally Cox, Sundays on NBC-TV

Flux coated metal-arc welding in a Reynolds plant.



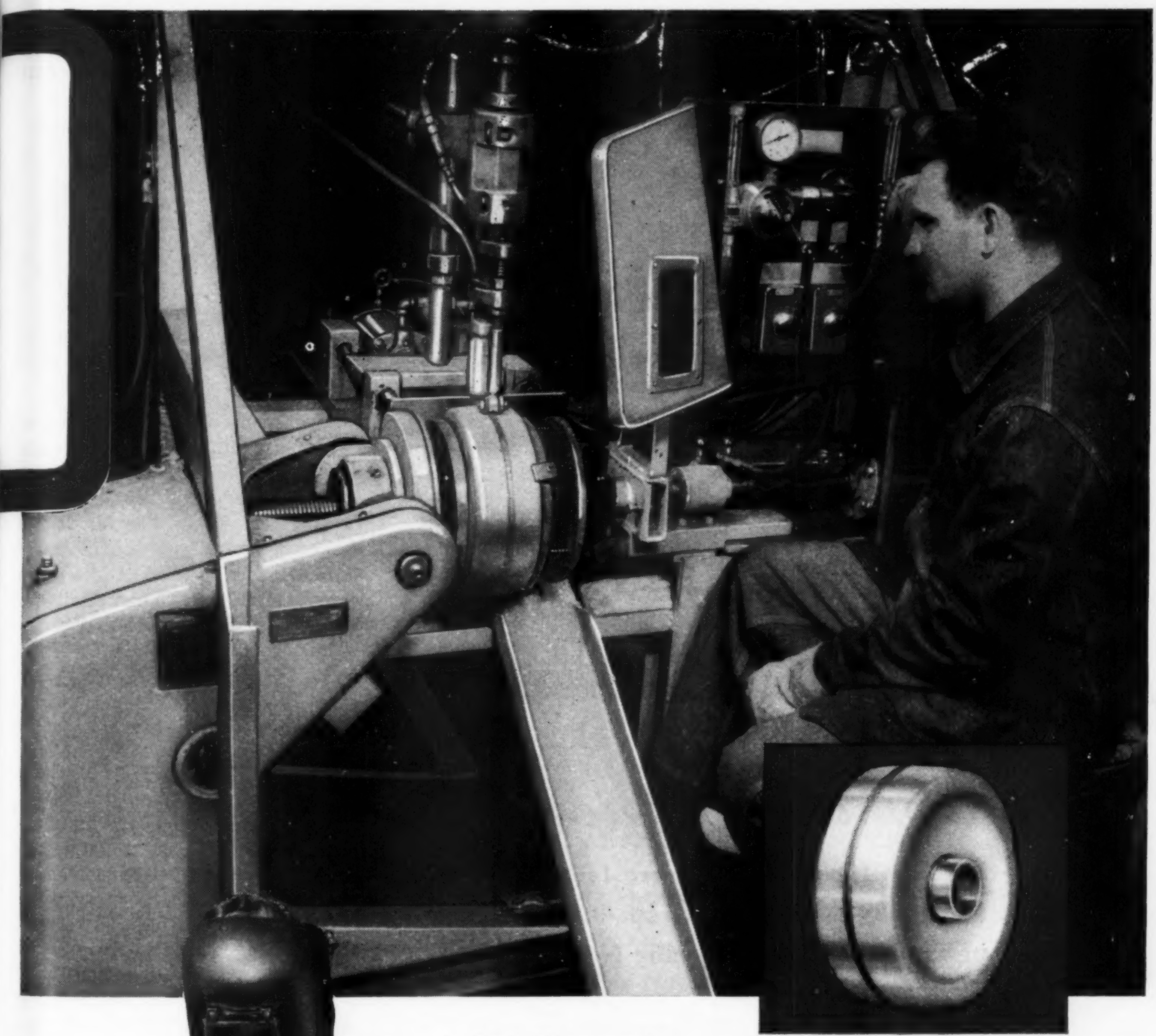
Reynolds plant photo showing flash welding of aluminum.



Spot welding clips to roll formed patio awning beam in a Reynolds plant.

REYNOLDS ALUMINUM

BLANKING · EMBOSSING · STAMPING · DRAWING · RIVETING · FORMING



Reynolds automatic fusion welding equipment. Small photo shows finished trailer wheel welded on this equipment in a Reynolds plant.

Inert-gas-shielded arc welding on aluminum tubing in a Reynolds plant.

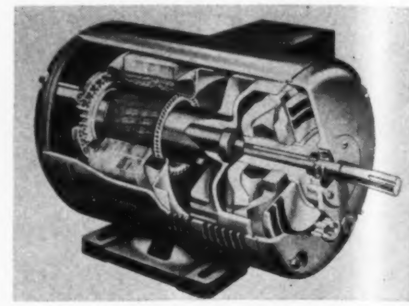
A conveyorized brazing furnace in a Reynolds plant.

FABRICATING SERVICE

ROLL SHAPING • TUBE BENDING • WELDING • BRAZING • FINISHING

New Parts

(*Continued from Page* 363)

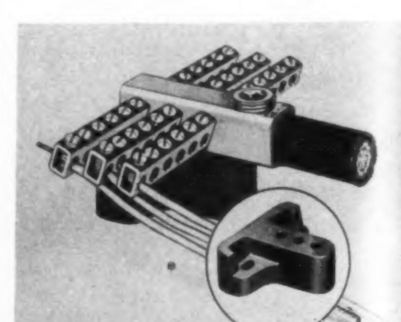


±2 per cent of the top speed at any point within the speed range which is from 0 to 3200 rpm with constant torque. Remote controls can be used, located as far as 100 ft away. Drives are available for standard single and three-phase power. Made by Dynamatic Div., **Eaton Mfg. Co.,** Kenosha, Wis.

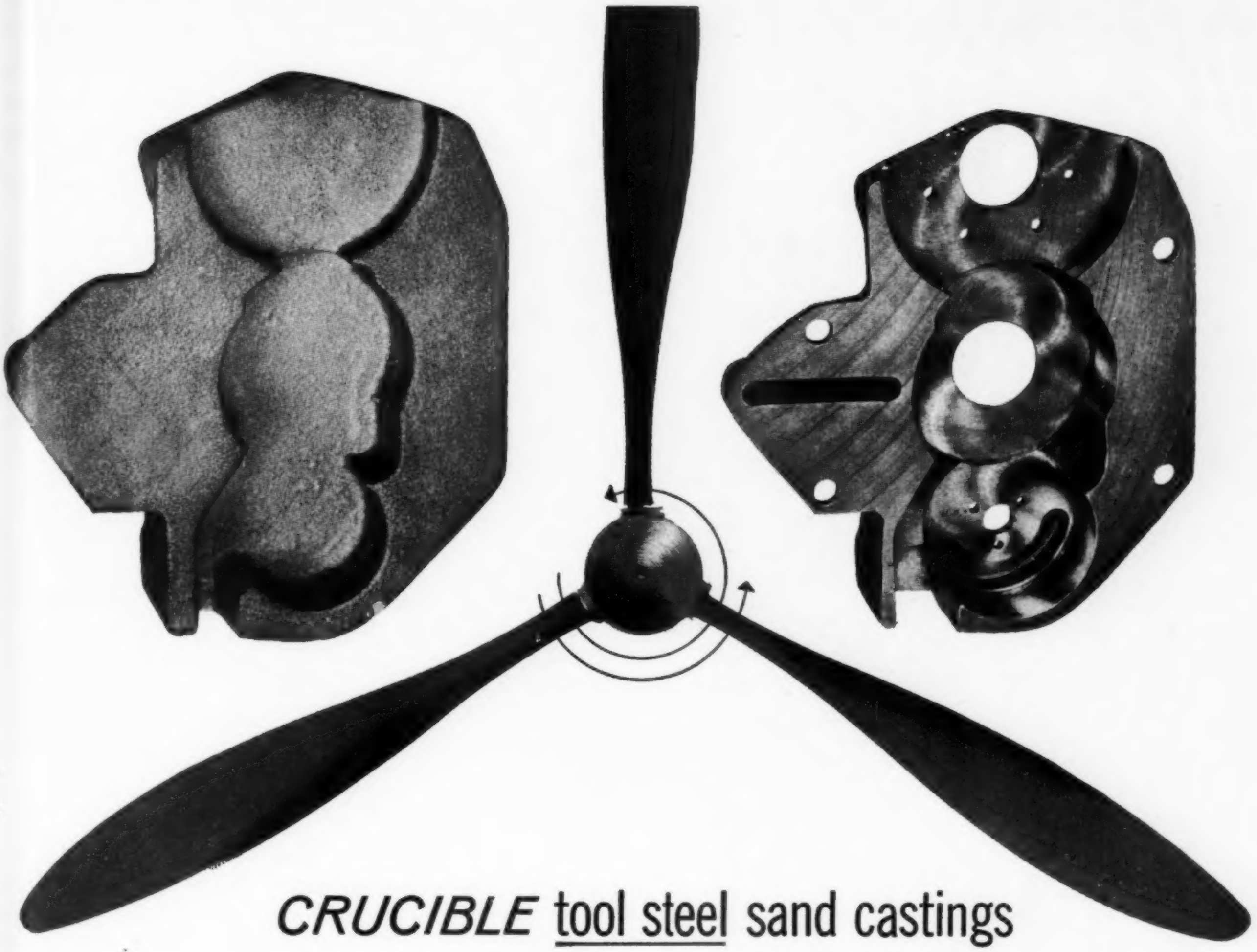
For more data circle MD-124, Page 297

Bar Type Connector

Compact CAN neutral bar is hard drawn seamless copper tubing. Circuit bars are forged into the main line connectors at a 20-degree angle to facilitate wire insertion of every branch circuit wire. Connections are made parallel to each other, wires do not spread away from the screw head, washer head screws are eliminated and forming or wiring of wires around and under the screw head is unnecessary.



Connection is made by inserting wires in V-shaped hole when screw is pulled down. Circuit taps take No. 14-6 wire, and the main line load is 250,000 cir mils-6. Main lug and circuit bars are forged together, eliminating the necessity of attaching separate line load connector. Models are available with



CRUCIBLE tool steel sand castings

end frequent replacement of aircraft propeller pump parts . . .

This AIRKOOL tool steel sand casting, a sump pump housing for an aircraft feathering propeller, adds valuable flying time between overhauls.

Originally made of magnesium, the housing wore down and had to be replaced frequently. Crucible castings engineers tackled the problem. Their solution: AIRKOOL castings of 5% carbon, air hardening tool steel. AIRKOOL's abrasion resistance, toughness, machinability, and nondeforming qualities when hardened, make it practical to cast to close tolerances. And although the walls of this part are sometimes less than 1/8" thick, it's heat treated to 55Rc with no discernable distortion.

Refer *your* production problems to Crucible. For Crucible castings engineers have both the *experience* and *production facilities* for quality castings — sand, investment, shell mold, green or baked core. When you need steel castings *call Crucible.*

CRUCIBLE first name in special purpose steels

54 years of Fine steelmaking

AIRKOOL SAND CASTINGS

CRUCIBLE STEEL COMPANY OF AMERICA, GENERAL SALES OFFICES, OLIVER BUILDING, PITTSBURGH, PA.

REX HIGH SPEED • TOOL • REZISTAL STAINLESS • ALLOY • MAX-EL • SPECIAL PURPOSE STEELS

Canadian Distributor — Railway & Power Engineering Corp., Ltd.

New Parts

24, 30, 36 or 42 circuit taps. Made by **Ilsco Copper Tube and Products Inc.**, Mariemont Ave., Cincinnati 27, O.

For more data circle MD-125, Page 297

Blind Fastener

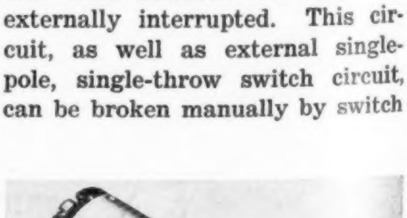
One-piece Q-4 fastener resists severe and prolonged vibration. In use, it is snapped into place in the outer sheet or panel, the two

panels to be joined are pushed together, and the fastener is given a one-quarter turn to lock. Fastener is self-retaining in outer panel and accommodates commercial sheet metal tolerances. Sizes are available for various panel thicknesses. Made by Shakeproof Div., **Illinois Tool Works,** St. Charles Rd., Elgin, Ill.

For more data circle MD-126, Page 297

Holding Coil Switch

Series A1200 holding coil switch performs functions of a relay plus two conventional switches. Built-in solenoid holds switch on contact until solenoid coil circuit is externally interrupted. This circuit, as well as external single-pole, single-throw switch circuit, can be broken manually by switch



knob. Snap-action device has life in excess of 25,000 make-and-break cycles at rated load. Mechanism is enclosed for operation in humid or corrosive atmospheres. Switch weighs 3 oz and is 3⅜ in. long. Contacts are rated at 5 amp inductive load at 30 v dc. Switch meets MIL specifications. Made by **Hetherington Inc.,** Sharon Hill, Pa.

For more data circle MD-127, Page 297

Standard Shafts

For use in many types of equipment, shafts and assemblies permit flexible standardization through wide choice of design. Unplated, cadmium or copper plated steel shafts include varied

diameters on a single shaft, snap-ring grooves, "D" or double "D" flats, knurling for bushings, and end-knurling for finger-tip actuation. Special control shaft assemblies, with or without cams, can be supplied ready for immediate chassis - mounting with flanged brass or steel externally threaded bushings. Made by **Fox Products Co.,** 4720 N. Eighteenth St., Philadelphia 41, Pa.

For more data circle MD-128, Page 297

Aluminum Alloy

Good weldability is exhibited by K186, a high-strength, non-heat-treatable aluminum alloy developed for structural applications. Alloy has nominal composition of 4.0 per cent magnesium, 0.45 per cent manganese and 0.10 per cent chromium. Depending on temper, tensile strength ranges from 38,000

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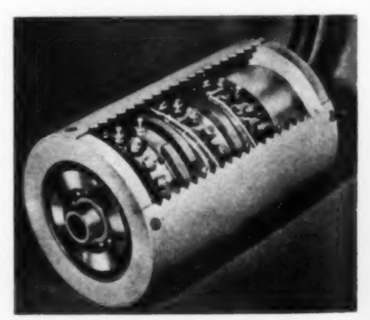
Standard and Special Ball Thrust Bearings • Angular Contact Ball Bearings • Special Roller Bearings • Ball Retainers • Hardened and Ground Washers • Sleeves • Bushings • Miscellaneous Precision Parts

to 47,000 psi, yield strength from 17,000 to 37,000 psi and elongation between 10 and 22 per cent in 2 in. Formability and resistance to corrosion are good. Material is available in 12 to 90 in. flat sheet widths and up to 60 in. wide as coil. Plate ranges from 0.250 to 2.250 in. gages and up to 96 in. wide. Standard and anodized finishes can be applied. Developed by **Kaiser Aluminum & Chemical Corp.**, 1924 Broadway, Oakland 12, Calif.

For more data circle MD-129, Page 297

Power Digitizer

Quantor power digitizer, handling currents of 5 amp, converts shaft positions into digits. It can operate I.B.M. summary punches, relays, hydraulic and pneumatic solenoid valves and similar equipment directly, without the need of

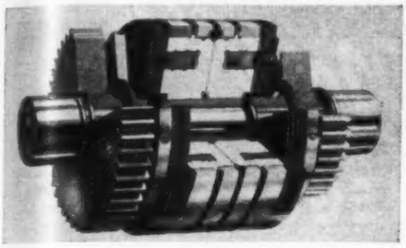


amplifiers. Ball bearing construction effects low operating torques. Separate digitizing and power circuits are used within the compact digitizer unit to obtain high power capacity. Digitizer has no vacuum tubes. It is 5.7 in. long and 3.5 in. in diameter. Made by EE Div., **Oerlikon Tool & Arms Corp. of America**, Asheville, N. C.

For more data circle MD-130, Page 297

Electromagnetic Clutch

Electro Clutch fits the requirements of a transmission which employs constant mesh gearing. Design provides constant horsepower output, quiet operation and rapid speed change. Clutch is controlled by a 24-v dc circuit. No field adjustment of torque value can be

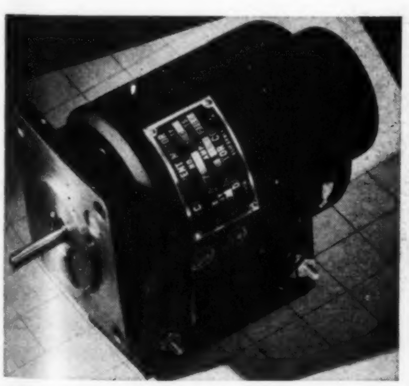


made. Self-compensating clutch requires no adjustment for wear of plates. Made by Rectifier Div., **I-T-E Circuit Breaker Co.**, 601 E. Erie Ave., Philadelphia 34, Pa.

For more data circle MD-131, Page 297

Constant-Speed Motor

Engineered to meet requirements of a speed-regulated, radar-antenna spin motor, type SC-23 motor maintains a constant governed speed of 7100 rpm $\pm$ 1 per cent, operating on 24 to 30 v dc and with load variations of $\pm$ 30 per cent. A radio-noise filter is mounted directly on the motor frame,



and carrying power terminals are provided for input voltage. Motor is rated for continuous duty and provides a locked-rotor torque of 9⅝ lb-in. Total weight is 5.5 lb. Made by **Dalmotor Co.**, 1347 Clay St., Santa Clara, Calif.

For more data circle MD-132, Page 297

Impulse Generators

Converting mechanical energy into pulses of electrical energy, series B7000 impulse generators emit electrical impulses upon application of only slight mechanical

NEW *Norgren* REGULATORS give close, constant pressure control of cylinder gases . . .

. . . plus EASIER MAINTENANCE
and a lot less of it!

Norgren 1-stage Cylinder Gas Regulators are specially built to regulate the pressure of cylinder gases, from tank supply to point of use, as accurately as most 2-stage types. Outstanding features include: close control in reducing tank pressures of up to 3000 psi. to delivery pressures from 2 psi. to 450 psi.; positive delivery pressures without "creep"; exclusive ball-pivoting lower spring rest which assures permanently friction-free operation; available with maximum delivery pressures of 50, 75, 175 or 450 psi.

FOR USE ON FOLLOWING GASES:

Carbon Dioxide
Nitrous Oxide
Nitrous Oxide and Carbon Dioxide Mixtures
Carbon Monoxide
Ethane
Ethylene (Industrial)
(Medical)
Hydrogen
Methane

WATER PUMPED:

Air
Argon
Helium
Krypton
Neon
Nitrogen
Xenon

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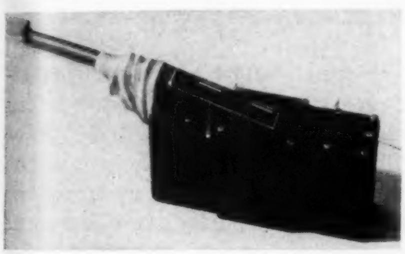
Manufacturers of Quality Pressure Regulators for more than a Quarter of a Century

PIONEER AND LEADER IN OIL FOG LUBRICATION FOR 26 YEARS

C. A. *Norgren* CO.
3442 So. Elati, Englewood, Colo.

Valves • Filters • Regulators • Lubricators • Hose Assemblies

force. Units are self-restoring after operation without application of additional mechanical force, and they operate successfully under water without impairment of electrical characteristics. No potential energy is stored, eliminating the possibility of premature or unintentional operation. Model illustrated delivers 5½ w power for pulse duration of 25 milliseconds or longer with fast rise time and

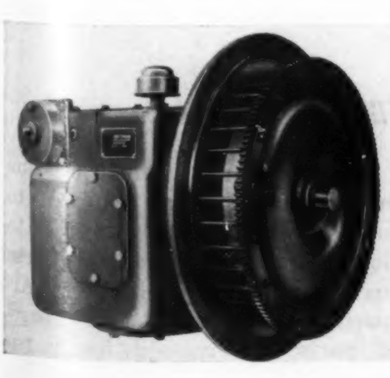


minimum pulse lag and decay. It measures 5½ x 2 x 3¾ in. and weighs 2¾ lb. Size, shape and weight are variable to meet a wide range of operating requirements of space, mechanical force input, desired electrical energy outupt and weight, and the generators are available hermetically sealed. Made by **Microloc,** 5811 Marilyn Ave., Culver City, Calif.

For more data circle MD-133, Page 297

Heavy-Duty Transmission

Compound double planetary type transmission is rated at 150 lb-ft continuous input torque. Transmission consists of two planetary gear assemblies for low and reverse, plus a multiple disk clutch for direct drive. The planetaries are actuated when hydraulic pressure contracts a band around an annulus or drum to provide the desired

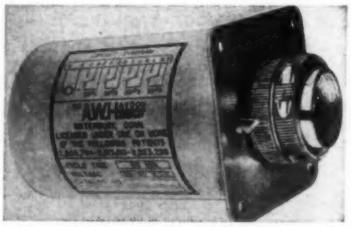


movement. Bands are returned to open positions by spring pressure. Controlled by one hydraulic valve lever, transmission can be shifted rapidly, without vibration or jerking. Standard gear ratios are 1 to 1 in high, 3 to 1 in low and 3.2 to 1 in reverse; optional low is 2.23 to 1. Made by **American Gear & Mfg. Co.,** Lemont, Ill.

For more data circle MD-134, Page 297

Repeat Cycle Timers

Hermetically sealed miniature repeat cycle timers are motor-driven and can be supplied with 50, 60 or 400-cycle per second ac motors, as well as standard or governed dc motors. Low power requirement of the motors makes timers suitable for both local and remote control applications or continuous duty. Cycling time depends upon motor

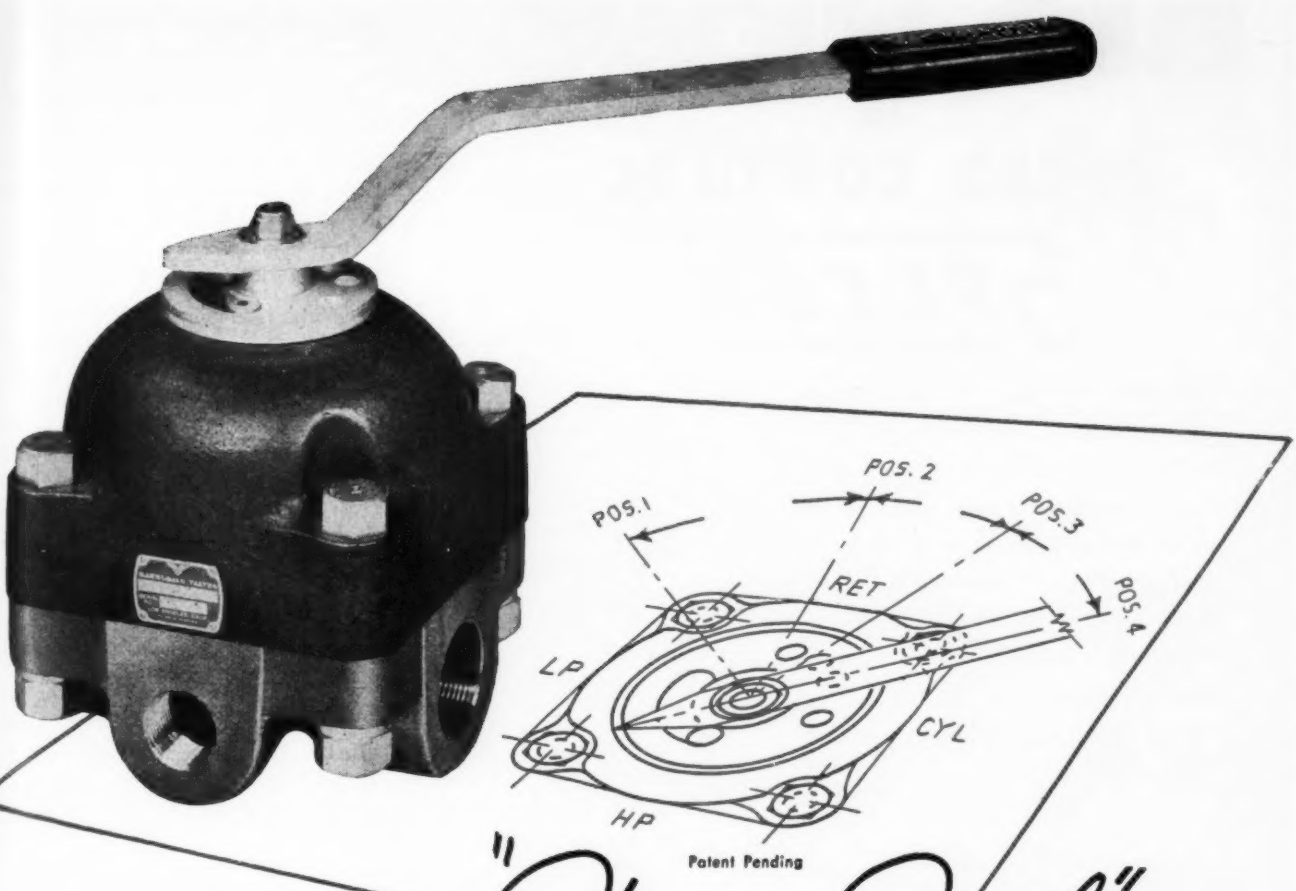


speed, and motors can be supplied with output speeds from 10 rpm to 1 revolution per 2 hours, 1 revolution per 40 minutes or 1 revolution per day. Intercam reductions up to 960 to 1 can be provided to allow high-speed pulsing with an extended cycle time. Units are available with flange mounting, as shown, or with three-stud mounting; with an AN connector as shown or a glass-metal header. Made by **A. W. Haydon Co.,** 230 N. Elm St., Waterbury, Conn.

For more data circle MD-135, Page 297

Silicone Rubber Adhesive

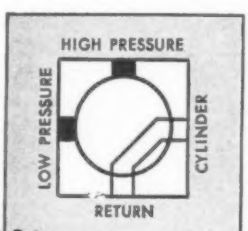
Uniform film of A-4000 silicone rubber adhesive may be used to bond silicone rubber to itself or to aluminum, magnesium, stainless steel, butyl or Saran rubber. Allowed to air dry until tacky, coated parts are pressed firmly to-



"Shear-Seal"

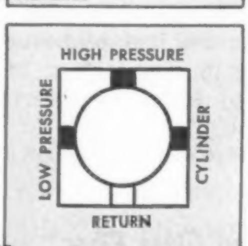
DUAL PRESSURE VALVES

WATER AND OIL SERVICE TO 3000 P. S. I.



POS. 1: Fast Return

POS. 2: Fast Advance



POS. 3: Stop

POS. 4: Bump and Squeeze

Especially developed to improve the control of accumulator operated presses. Effortless manipulation of the valve, with one hand, puts the press under your absolute control (see flow diagrams). The first and second position provide *fast* "return" and "advance" with throttling in between for "inching" the press to any desired degree. The "stop" position gives the operator a chance to hold everything instantly, perhaps to *check* rather than *wreck* the dies. And finally the high pressure position serves for "bumping" and the "squeeze." The most important reason why such a maneuverable valve is possible, lies in the *leak-proof* feature of the Barksdale "Shear-Seal" principle and its characteristic improvement with use.

For more complete information write for bulletin BVM-2 describing the "Shear-Seal" principle and Catalog 3G covering the valves.

BARKSDALE VALVES

QUALITY RELIABILITY COURTESY SERVICE

5125 ALCOA AVE., LOS ANGELES 58, CALIF.

gether to eliminate air bubbles. Curing takes place without further pressure in 24 hours at room temperature. Maximum bond strength is realized in 3 to 7 days. In general, a stronger bond is formed with extrusions than with molded silicone rubber. Heat and creep resistance are exhibited at temperatures through 100 C. Peel strengths of 15 psi have been obtained between extruded Silastic and aluminum. Made by **Dow Corning Corp.**, P. O. Box 592, Midland, Mich.

For more data circle MD-136, Page 297

Electronic Speed Control

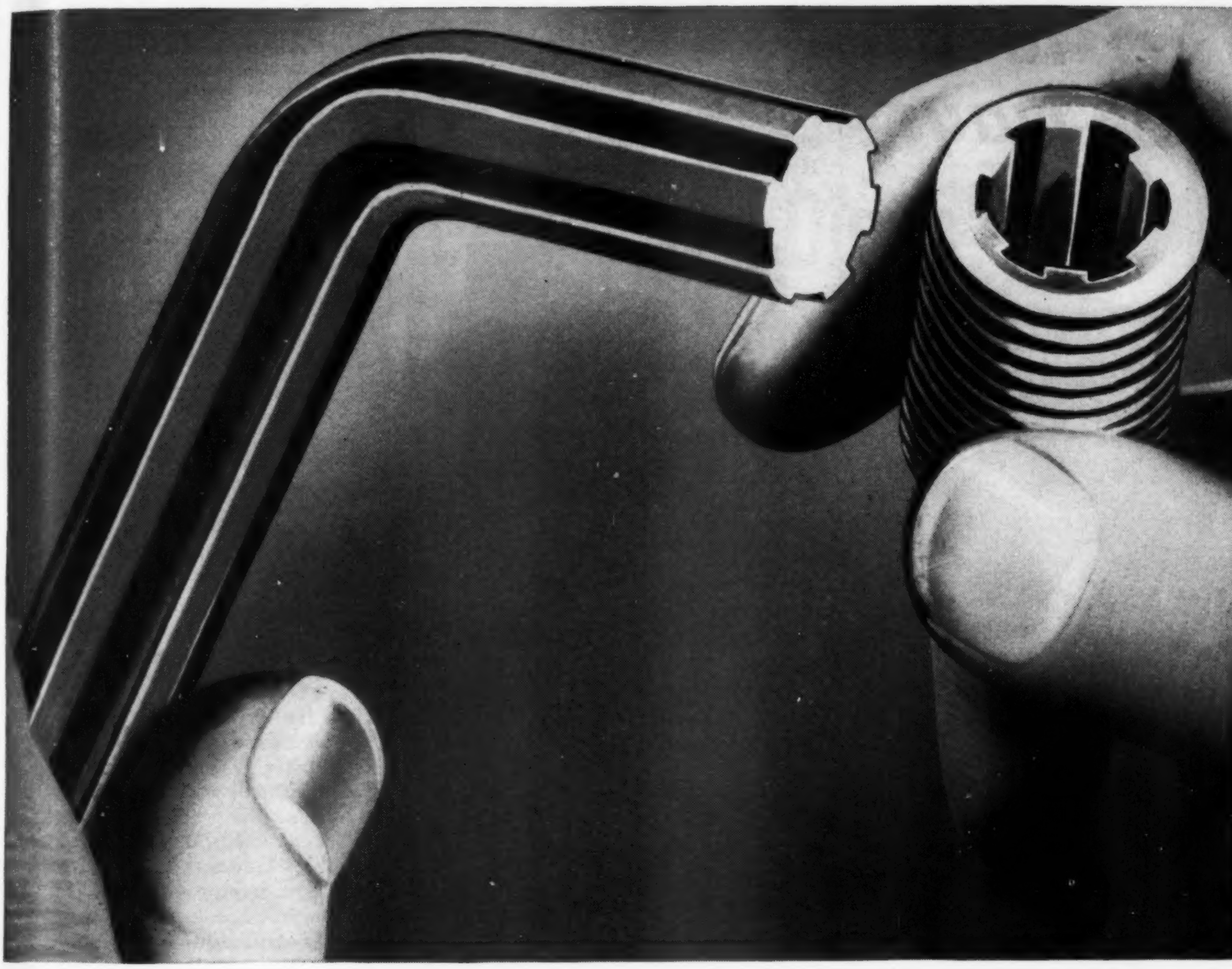
With a life expectancy of over 100,000 hours, this speed control offers instantaneous warm-up and speed variation from 0 to rated rpm. Constant torque is available

within a speed range of 25 to 1. Motors deliver from 1/20 to 2 hp and are available with dynamic braking and instantaneous reverse. Cabinet measures 9 x 16 x 8 in. Made by **Erdco Engineering Corp.**, Addison, Ill.

For more data circle MD-137, Page 297

Molded Glass Fiber

Gaskets, motor mounts, filters, preformed insulation, baffles for air conditioning units, and automobile instrument panels are among the many uses of molded or high-density Fiberglas. Product is almost 100 per cent glass with only a small amount of binder



Multiple-Spline Set Screws hold tighter— because you can wrench them tighter!

The extra holding power of Bristol's exclusive multiple-spline set screws enables these flush-fitting fasteners to be used in the newest, most compact design applications.

They withstand severe shock and vibration, permitting fewer and smaller screws to be used without sacrificing strength.

While the splining principle has long been recognized as the best means of transmitting rotary power, the materials of which they are made also contribute to the tremendous holding strength of these Bristol set screws. Standard screws are made of heat-treated alloy steel; bronze, brass, monel or other metals are available on special order.

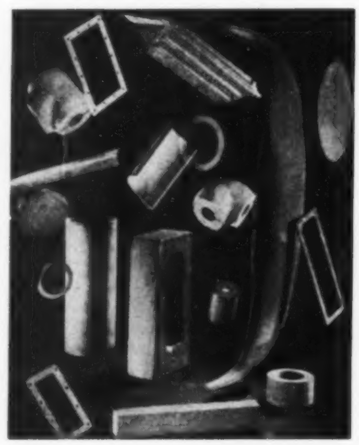
Bristol multiple-spline set or cap screws are carefully designed to close tolerance (ASA approved) in sizes from 0 wire to ½" in diameter. Get them through your regular industrial distributor.

BRISTOL'S SOCKET SCREWS

THE BRISTOL COMPANY, Socket Screw Division, Waterbury 20, Conn.

New Parts

to give structural integrity after curing. Material will not rot, burn, absorb moisture, shrink or stretch. It has thermal and acoustical in-

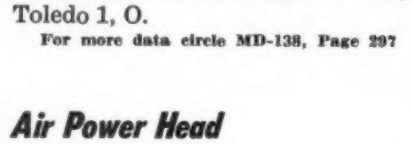


sulating properties and structural strength and rigidity. It can be made in densities up to 20 lb per cu ft, at which point it bears a resemblance to wood. Made by **Owens-Corning Fiberglas Corp.,** Toledo 1, O.

For more data circle MD-138, Page 297

Air Power Head

Model D 50 air power head has 1-in. stroke, attains 5 tons pressure and is suitable for production operations such as pressing, staking and riveting. Suitable for vertical or horizontal mounting, unit



operates on air pressures up to 150 psi with a ratio of 100 to 1. Diameter of ram is $1\frac{1}{2}$ in. Overall size of the power head is $6\frac{1}{2}$ x $6\frac{1}{2}$ x 16 in. long; weight is approximately 100 lb. Made by **Air-Hydraulics Inc.,** 268 Belden Rd., Jackson, Mich.

For more data circle MD-139, Page 297

DESIGN and PRODUCTION NEWS

FOR DESIGN AND MATERIALS ENGINEERS

Published by TECHNICAL SERVICE, Chemical Manufacturing Division, The M. W. KELLOGG Company OCT.-NOV. 1954

Smaller, Lighter Rupture Discs... Lined With KEL-F® Plastic... Now Used In Highly Corrosive Systems

Using coatings and seals of KEL-F plastic to overcome corrosion, lightweight, small rupture discs of aluminum now provide protection for low pressure and vacuum vessels. Discs with bursting pressures ranging from 5 to 100 psig are now possible. Premature bursting due to corrosion has been eliminated. Discs are smaller and afford a greater degree of pressure control than previous types.

A lining of KEL-F plastic on the standard (right) and a film seal in the new "lug" type rupture disc (left) permit them to be used safely with practically all corrosive materials, at temperatures up to 250°F.

Black, Sivalls & Bryson, Inc., Kansas City, Mo. manufacturers of control equipment, pioneered this use of KEL-F plastic film.

For further information ask for Application Report C-119

For complete information regarding any item mentioned in DESIGN AND PRODUCTION NEWS, ask for detailed APPLICATION REPORTS, write

Technical Service
CHEMICAL MANUFACTURING DIVISION
THE
M. W. KELLOGG
COMPANY
P.O. Box 169, Jersey City 3, N. J.
or offices in Boston, Chicago, Dayton
Los Angeles and New York

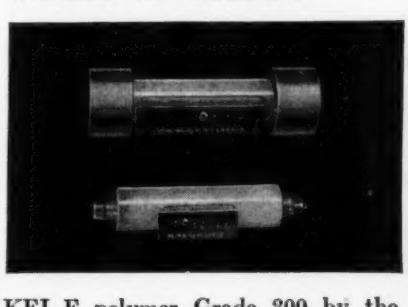
KELLOGG PULLMAN

HF at 300°F Handled by Flowmeters of KEL-F® Plastic In Atomic Plant ...Still "On Stream" After 2 Years!

Clarity, dimensional stability, accuracy and damage resistance make these flowmeters made from KEL-F polymer outstanding. In contact with extremely corrosive hydrogen fluoride for two years on low-pressure purge lines, they show no signs of "giving up".

Chemically-inert, the plastic tubes are unattacked by the HF even at 300°F. Machined to precision dimensions, they maintain original metering accuracy. Flow tubes have remained clear to permit easy float visualization.

The Brooks Rotameter Company, Lansdale, Pa., produces these corrosion-resistant flowmeters. Flow tubes are machined of rod extruded from



KEL-F polymer Grade 300 by the United States Gasket Company, Camden, New Jersey.

For further information ask for Application Report C-120

® *Registered trade-mark for The M. W. Kellogg Company's fluorocarbon Polymers.*

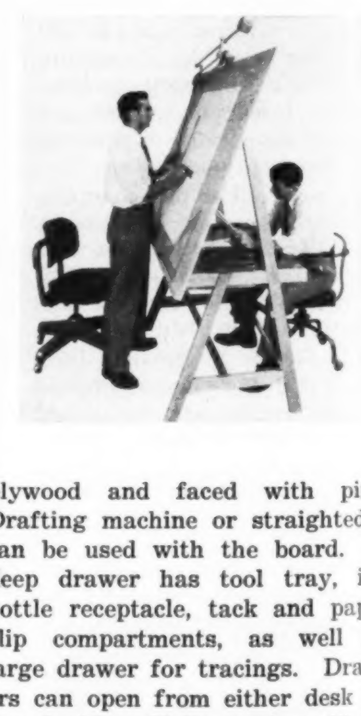
KEL-F
TRIFLUORO CHLORO ETHYLENE POLYMERS
KEL-F
MOLDING POWDERS
KEL-F
FLUORO CHLORO CARBON PLASTIC
KEL-F
DISPERSION COATINGS
KEL-F
TRIFLUORO CHLORO ETHYLENE POLYMERS
KEL-F
OILS WAXES GREASES

ENGINEERING
DEPARTMENT

EQUIPMENT

Vertical Drawing Board

Vertically adjustable Power-Slide drawing board and desk combination permits quick adjustment of board height without the use of levers or knobs. Board can be adjusted for use from either standing or sitting position. Moisture sealed, crack-proof 48 x 72-in. drawing surface is made of light

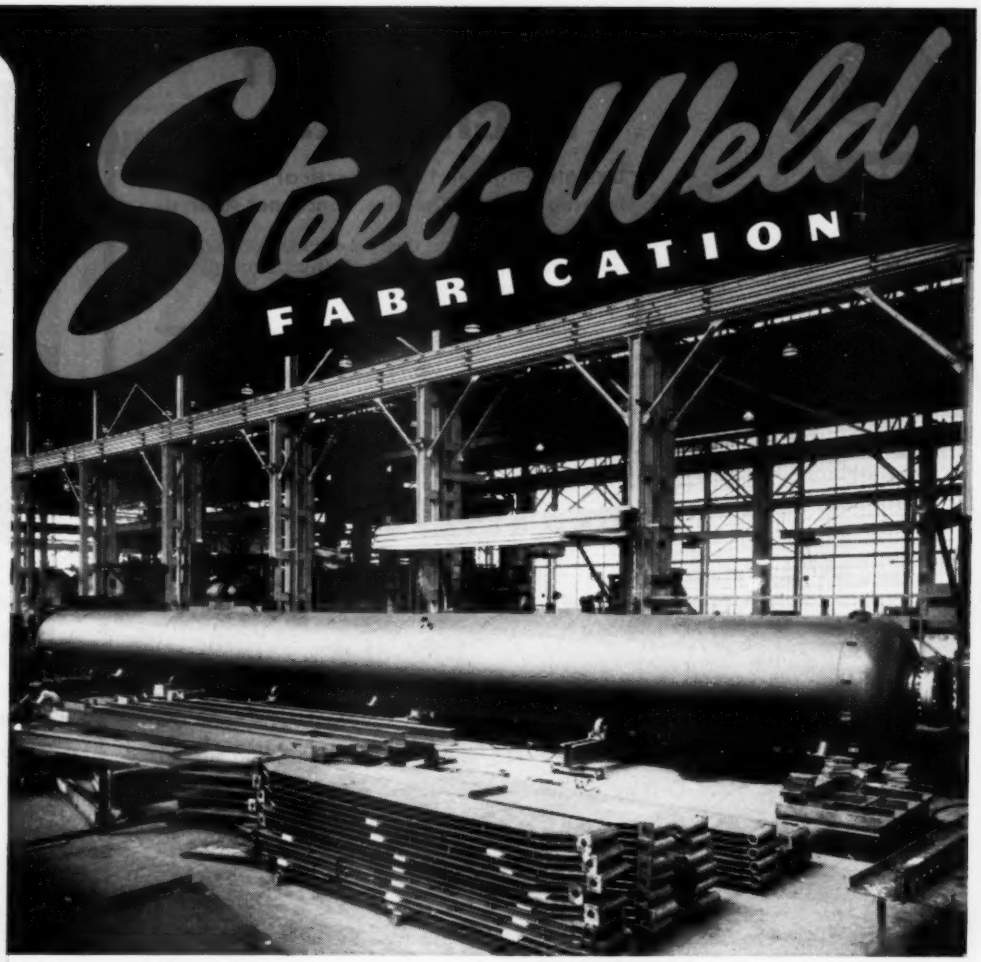


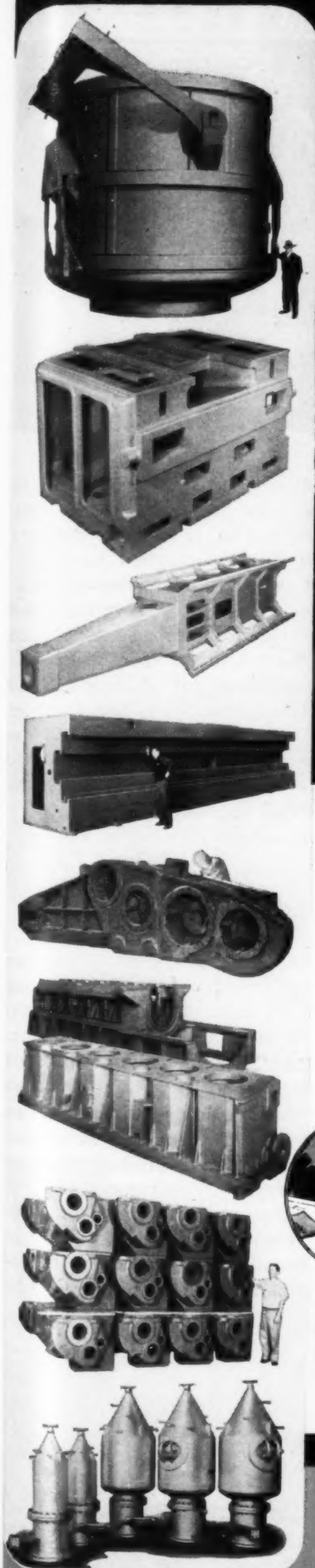
plywood and faced with pine. Drafting machine or straightedge can be used with the board. A deep drawer has tool tray, ink bottle receptacle, tack and paper clip compartments, as well as large drawer for tracings. Drawers can open from either desk or board side. Unit requires 15 sq ft of floor area. Made by **Power-Slide Drawing Board Co.,** 58 Emmons St., Milford, Mass.

For more data circle MD-140, Page 297

Whiteprinter

One-step automatic Challenger whiteprinting machine reproduces anything typed, written, drawn or photographed on translucent material. After exposure to light source, print is conveyed into developer and tracing is returned to operator. Printer and developer





Use WELDED STEEL for Greater Strength with Less Weight!

The 86-foot pressure vessel illustrated above is a Stabilizer built for a petroleum refining plant. This unit and its Overhead Receiver were Steel-Weld Fabricated by Mahon in accordance with the A.S.M.E. 1952 Code. Platforms, Ladders, and other miscellaneous iron, to complete this unit in the field, were also produced by Mahon. Equipment of this type, and the products, parts and assemblies shown at the left are typical of thousands of Steel-Weld Fabricated units produced and machined by Mahon for hundreds of processing plants and manufacturers of processing machinery, machine tools, and other types of heavy mechanical equipment. Perhaps you, too, could profit by discussing this unique service with a Mahon engineer. If you require special equipment, or parts or assemblies including large, heavy pieces, where time and pattern costs are a consideration, Mahon Steel-Weld Fabrication may prove to be the answer. You can turn to Mahon with complete confidence . . . personnel and facilities are available within the Mahon plant to do the entire job from drawing board to finished machining. You will find in the Mahon organization a reliable source with ultramodern fabricating, machining and handling facilities to cope with any type of work regardless of size or weight. See Mahon's Insert in Sweet's Product Design File, or have a Mahon engineer call at your convenience.

THE R. C. MAHON COMPANY

DETROIT 34, MICHIGAN

Engineers and Fabricators of Steel in Any Form for Any Purpose

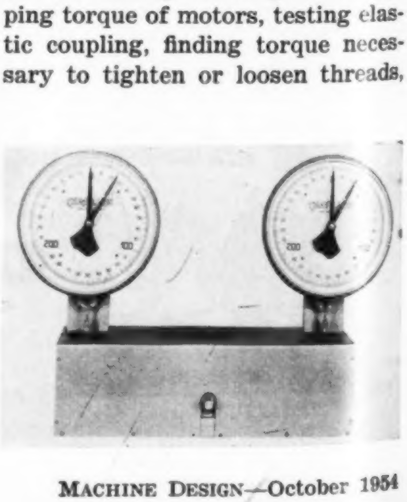
MAHON

are synchronized to produce up to 42-in. wide prints at 1 to 40 fpm. Light source is 4000-w mercury vapor lamp, controlled by a constant wattage transformer. Machine has large Formica feed table, electronic speed control, and metered ammonia control, as well as provision for delivering and stacking prints at either front or rear. Front and rear windup device is an optional accessory. Made by **C. F. Pease Co.,** 3998 N. Rockwell St., Chicago 18, Ill.

For more data circle MD-141, Page 297

Portable Torque Tester

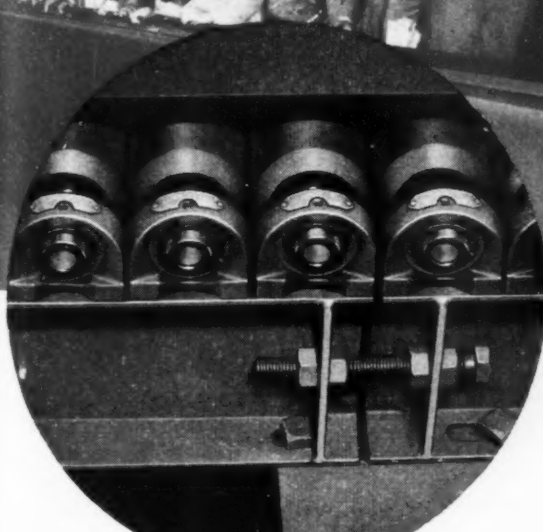
Redesigned Model No. 574 torque tester is available in capacities from 50 oz-in. through 1000 lb-in. and in graduations from 0.25-oz-in. through 4 lb-in. Built with two dynamometer heads, it can be used for clockwise or counterclockwise measurements from the same side. Accurate to one graduation or to specifications, instrument is used for measuring starting and stopping torque of motors, testing elastic coupling, finding torque necessary to tighten or loosen threads,



SEALMASTER
BALL BEARING UNITS

Keep People Moving, too

... ON THE STEPHENS-ADAMSON—GOODYEAR SPEEDWALK



WORLD'S FIRST SUCCESSFUL COMMERCIAL PASSENGER CONVEYOR BELT ROLLS ON 1200 SEALMASTER BEARING UNITS!

On May 24, 1954, weary New York commuters had their first ride on the Stephens-Adamson, Goodyear "Speedwalk"—world's first commercial passenger conveyor belt. Located in the Hudson and Manhattan Railroad Company's Erie Tube Station, the moving rubber belt transports passengers 227 feet—110 feet of which is 10% upgrade.

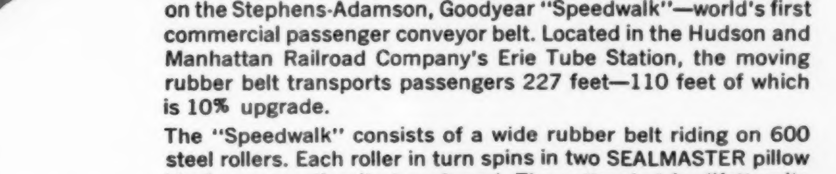
The "Speedwalk" consists of a wide rubber belt riding on 600 steel rollers. Each roller in turn spins in two SEALMASTER pillow blocks, supporting it at each end. These "sealed for life" units are designed for many years of maintenance-free service. Special housings allow the close spacing of rollers necessary for a smooth passenger ride. Head and tail pulley shafts on the "Speedwalk" also turn in SEALMASTER BEARINGS.

A new, efficient, safe and low cost mode of transportation has been developed in the "Speedwalk". SEALMASTER engineers are happy to have had an important role in its design.

For full information see your SEALMASTER Distributor or write the factory. SEALMASTER Distributors are located in all principal cities.

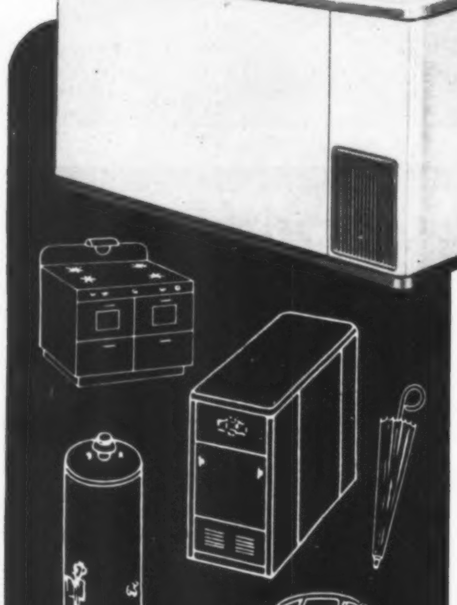
SEALMASTER

BALL BEARING UNITS



SEALMASTER BEARINGS A DIVISION OF STEPHENS - ADAMSON MFG. CO · 18 RIDGEWAY AVE., AURORA, ILL.

The Tube Line That Rates a Buy-Line!



IN THE DESIGN and building of the products shown here, GM Steel Tubing plays an important part—either for the passage of liquids or gases, or as part of the mechanical structure. And these are but a few of the thousands of manufactured items that use low-cost steel tubing in place of more expensive materials. Examine your own requirements! You, too, may find you can *improve design, speed production,* and *cut costs* with "The Tube Line That Rates a Buy-Line"—GM Steel Tubing!

SEE SWEET'S PRODUCT DESIGN FILE $\frac{1a}{Ro}$

RP

GM STEEL TUBING

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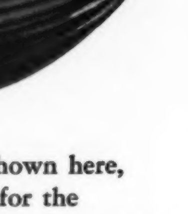
This new, illustrated, fact-packed brochure tells how GM Steel Tubing can help solve design and production problems. Send today for your free copy.



ROCHESTER PRODUCTS

DIVISION OF GENERAL MOTORS, Rochester, N. Y., U.S.A.

ALSO MANUFACTURERS OF ROCHESTER CARBURETORS AND ROCHESTER CIGAR LIGHTERS

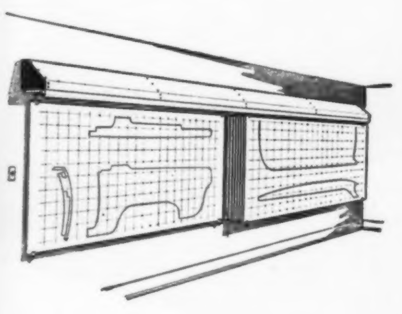
Engineering Equipment

and testing impact wrenches. Made by **John Chatillon & Sons,** 85-93 Cliff St., New York 38, N. Y.

For more data circle MD-142, Page 297

Large-Layout File

Designed to facilitate filing of large layouts to keep them readily accessible, Roll-A-Way filing system consists of a rack with a number of parallel tracks from which layouts are suspended. Rack is twice the width of layout or drawings, so that the one required



can be quickly rolled out from its filing place into full view. Racks can be built with any number of tracks to accommodate both thin metal and thick Celotex or Masonite layouts. They are built to specified lengths and can be caster-stand or wall-mounted. Wall model is fluorescent lighted. Made by **Inter-Lakes Engineering Co.,** 4845 Bellevue Ave., Detroit 7, Mich.

For more data circle MD-143, Page 297

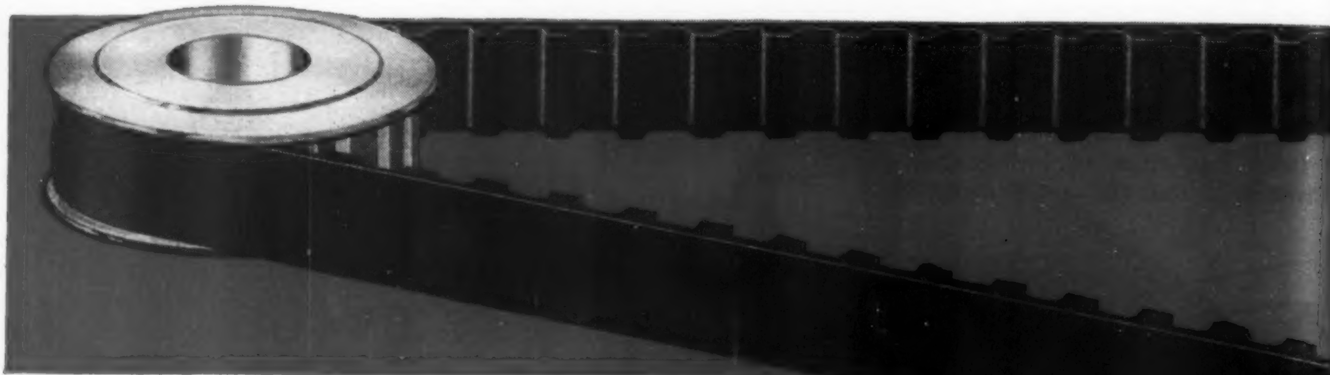
Adjustable Power Supply

Model 701 unregulated power supply provides dc voltages to 250 v at maximum load of 90 ma (360 v, open circuit), and ac filament power, 6.3 v at 3 amp, center tapped. Ripple is kept to 20 mv rms by use of a two-section choke input filter. Auto transformer permits adjustment of output. Output voltage is constantly monitored. Separate terminals for positive, negative and ground are provided. Made by Shasta Div., **Beckman Instruments Inc.,** P. O. Box 296, Richmond, Calif.

For more data circle MD-144, Page 297

Here's How the *Original*

Gilmer "TIMING"®



...made possible improved tool life and finishes on the

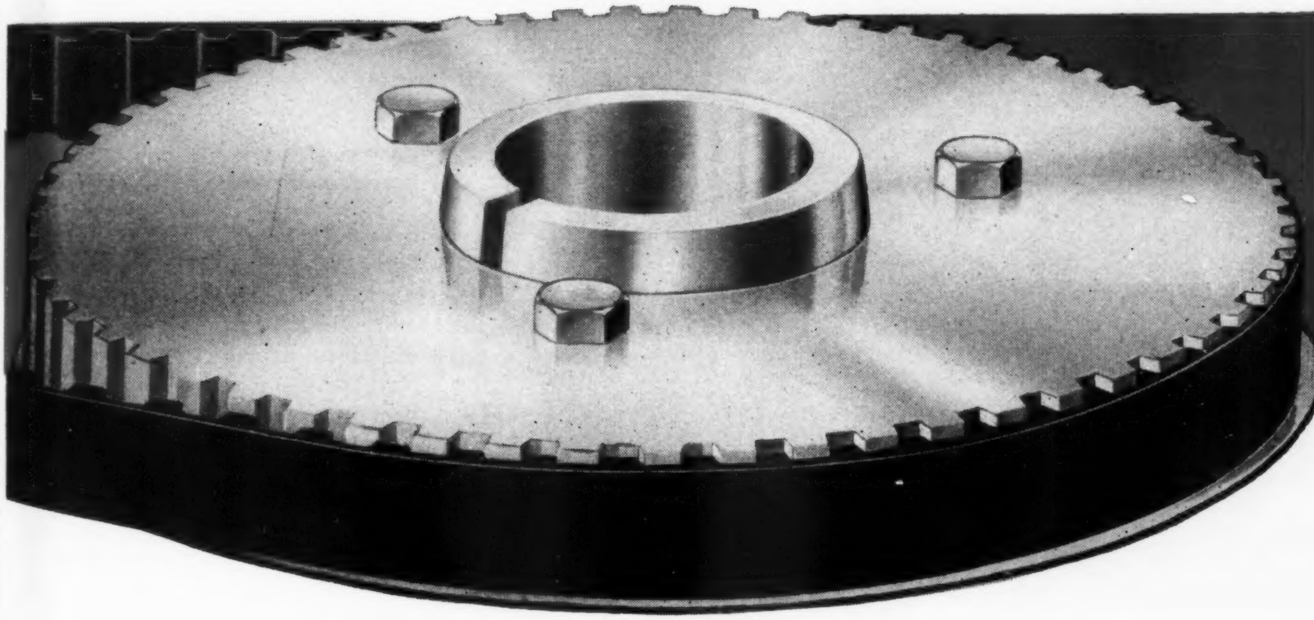
PRATT & WHITNEY AUTOMATIC DUPLICATING MACHINE

On this machine, the two upper and two lower cutter spindles, driven by Gilmer "Timing" Belt Drives, simultaneously produce four identical forging dies (such as for jet turbine blades) under control of the center *tracer spindle* which follows a hard master shape. The machine duplicates to very close tolerances, using either high-speed steel or carbide cutting tools.

Since the life of carbide tools is greatly reduced, and finish impaired, by any slippage or slowing down of the spindle drive, the round belts formerly employed not only required much larger-diameter pulleys but also produced unsatisfactory tool life, as some slippage was bound to occur. To hold this to a minimum, belts had to be installed under high initial tension, which also resulted in frequent belt breakage.

The answer to the problem proved to be a *positive* slip-proof drive requiring no initial tension, no lubrication, no large pulleys — the Gilmer "Timing" Belt Drive! Now, a total of eight "Timing" Belt Drives transmits perfectly synchronized power from the motor to the five spindles. Belt slippage and tool chatter is positively eliminated, assuring maximum life from carbide tools and uniformly high quality finishes on the work. Belt breakage is a thing of the past. Belt pulleys are considerably smaller, yet provide a speed range of 900 to 10,000 rpm required for the interchangeable use of high-speed steel and carbide cutting tools.

BELT DRIVE



Industry's Newest Power Transmitting Medium

SWEEPS AWAY DESIGN RESTRICTIONS

In one application after another, "Timing" Belt Drives have enabled machine designers to achieve basic engineering improvements—or to design entirely new machines—that were previously either impractical or impossible! For never before has there been a *positive drive* that combined all these desirable characteristics:

- **Requires no lubrication, no housings or lubricant guards.**
- **Maintains precise synchronization ("timing") between shafts.**
- **Provides speed ratios as high as 15 to 1 in a single step.**
- **Operates satisfactorily at speeds from inches per hour to 15,000 fpm.**
- **Permits use of very small diameter pulleys for ultra-compact drives.**
- **Has nearly 100% mechanical efficiency.**
- **Needs no initial tension. Lighter bearing loads permit lighter bearings.**
- **Does not stretch or lengthen with use; requires no take-up.**
- **Can be designed for zero backlash.**
- **Capacity ranges from 1/100 to 300 horsepower.**

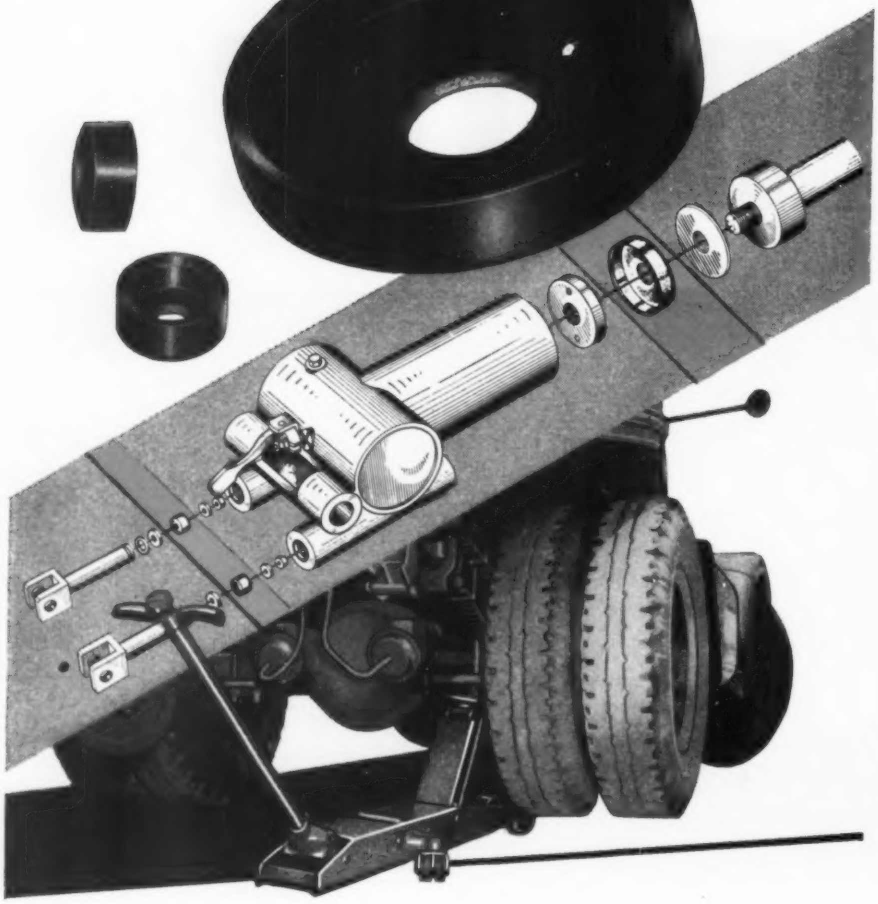
These are but a few of the unique features of this amazing tooth-grip belt drive that is already in successful use on hundreds of thousands of machines. Full details and description are given in the 76-page Gilmer "Timing" Belt Manual, which lists hundreds of drives available promptly from stock. For your copy, call your nearby Gilmer "Timing" Belt Distributor. Or, if he isn't listed in the classified telephone directory, write to the address below.

NEW YORK BELTING & PACKING CO. Founded 1846

NYB&P

NEW YORK BELTING & PACKING CO. 1 Market St., Passaic, N. J.

America's Oldest Manufacturer of Industrial Rubber Products



THE ENGINEER'S

Library

Recent Books

Elements of Electrical Machine Design. *By Alfred Still, professor emeritus of electrical engineering, and Charles S. Siskind, assistant professor of electrical engineering, Purdue University; 465 pages, 6 by 9 inches, clothbound; published by McGraw Hill Book Co. Inc., New York; available from* MACHINE DESIGN, *$9.00 postpaid.*

Emphasizing principles and practices of electrical machine design, this third edition is devoted primarily to rotating electrical machinery and transformers. It discusses basic design principles of electric, magnetic and electrostatic circuits. A plan is followed of first presenting discussions relating to materials of construction and their arrangements and proportions, then the derivation of useful design formulas, and finally the solution of illustrative examples.

Chapters cover dynamo machinery, armature windings and design, commutation and commutating poles, tooth reluctance and armature reaction, field magnets and windings, losses, ventilation, temperature rise, ac machinery, synchronous generators, polyphase induction motors, transformers, and mechanical design of electrical machinery.

Wire tables, magnetization curves, and core loss and volt-ampere curves appear in the appendixes.

•

Practical Gear Design. *By Darle W. Dudley, supervisor, gear advance and development engineering, General Electric Co.; 347 pages, 6 by 9 inches, clothbound; published by McGraw-Hill Book Co. Inc., New York; available from* MACHINE DESIGN, *$7.00 postpaid.*

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gear types, such as spur, helical, worm and bevel, the scope of this book includes geometry of gear design, manufacturing methods, uses, and causes of gear failures. Practical guidance is given for calculating load-carrying capacity of gears, choosing materials for their manufacture, sizing the parts for economical production, dealing with limitations imposed by gear-cutting tools, and handling gear operation problems under typical service conditions. Among many practical helps are data on shaving of gears, shear cutting and other advances; equations, curves and tables to aid in gear design; and guidance on kinds and causes of gear failure.

•

Elements of Structural Engineering. *By Ernest C. Harris, professor and chairman, department of civil engineering and engineering mechanics, Fenn College;* ***513 pages, 6 by 9 inches,*** *clothbound; published by The Ronald Press Co., New York; available from* **MACHINE DESIGN, $7.00** *postpaid.*

This textbook presents structural engineering from the point of view of mechanical, electrical and other noncivil engineers. Structural theory is brought out by applying it to cranes and conveyor supports rather than more conventional examples of bridges. Engineering principles inherent in design of buildings are exemplified by analyzing the effect of new electrical or mechanical equipment on safety of existing structures. Chapters cover equilibrium and reactions; shear, thrust and bending moments; analysis of trusses and bracing; analysis with moving loads; deflection in beams; and design in steel, concrete and timber. Tables of section properties, load data and symbols are included in the appendix section.

•

Organic Protective Coatings. *Edited by William von Fischer, head, department of chemistry and chemical engineering, and Edward G. Bobalek, associate professor of chemistry, Case Institute of Technology;* **395**

5 good reasons for specifying AMSCO® * MANGANESE STEEL

it is virtually nonmagnetic

Untransformed austenite of 13% manganese steel is virtually nonmagnetic. This permits its use where a strong, tough nonmagnetic metal is required, as in magnet cover plates, crane collector shoes and similar applications. And it is probably the most economical *strong* material for nonmagnetic parts if machining is not required.

it remains tough at low temperatures

Like most austenitic structures, manganese steel remains tough at extreme low temperatures. Even in arctic climates where lows to 100°F below zero may be encountered, it still retains a valuable safety factor. It has proved ideal for such applications as railway trackwork, mining equipment, etc.

it work-hardens

Manganese steel has no equal in its ability to work-harden, exceeding even the austenitic stainless steels in this respect. The maximum hardness practically attainable is about 550 BHN. But equally important, *manganese steel work-hardens at the point of wear.*

it resists wear

The combination of toughness and ductility, together with the work-hardening property of manganese steel, makes it an ideal metal for parts subject to impact coupled with abrasion.

it has slow crack propagation

The slow propagation rate on cracking provides a built-in safety feature. Early determination of impending failure can be seen and remedied, thus eliminating costly down time and possible damage to dependent parts or assemblies.

For a more complete technical discussion of manganese steel and its inherent design features, write for this free booklet.

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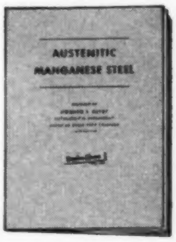

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AMERICAN MANGANESE STEEL DIVISION

Brake Shoe

Chicago Heights,
Illinois

pages, 6 by 9 inches, clothbound; published by Reinhold Publishing Corp., New York; available from MACHINE DESIGN, *$7.50 postpaid.*

Emphasizing the problems of formulation, specification and application of organic coatings, this book describes fundamental theory and practice of paint as an engineering material. Several chapters present such theoretical aspects as engineering properties of paint, paint formulation, pigment dispersion, reflective properties and reflectance spectrophotometry. Others offer typical case histories of progress in the coatings industry, including development of anticorrosive and luminescent pigments, aminoplastic resins, hot spray lacquers, emulsion and latex paints; protection of metal surfaces with synthetic resin coatings; new applications of organic coatings to electrical insulation; and the use of silicone resins in heat-resistant paints.

•

Airplane Structures—Volume 1. *By Alfred S. Niles, professor of aeronautic engineering, Stanford University, and Joseph S. Newell, late professor of aeronautical structural engineering, Massachusetts Institute of Technology; 623 pages, 5¾ by 9 inches, clothbound; published by John Wiley & Sons Inc., New York; available from* MACHINE DESIGN, *$7.75 postpaid.*

This textbook, a fourth edition, presents a study of the application of fundamental principles of stress analysis. Structural analysis methods are shown as essentially simple. So far as possible, detailed procedures are developed as special applications of the principles of equilibrium, consistent deformations and conservation of energy. Although procedures are discussed on the basis of importance to aeronautical engineers, they are equally applicable to many types of nonaeronautical structures, particularly those requiring a high strength-weight ratio.

Following an introductory chapter on general design requirements, subsequent chapters cover reactions, shear, bending moments,

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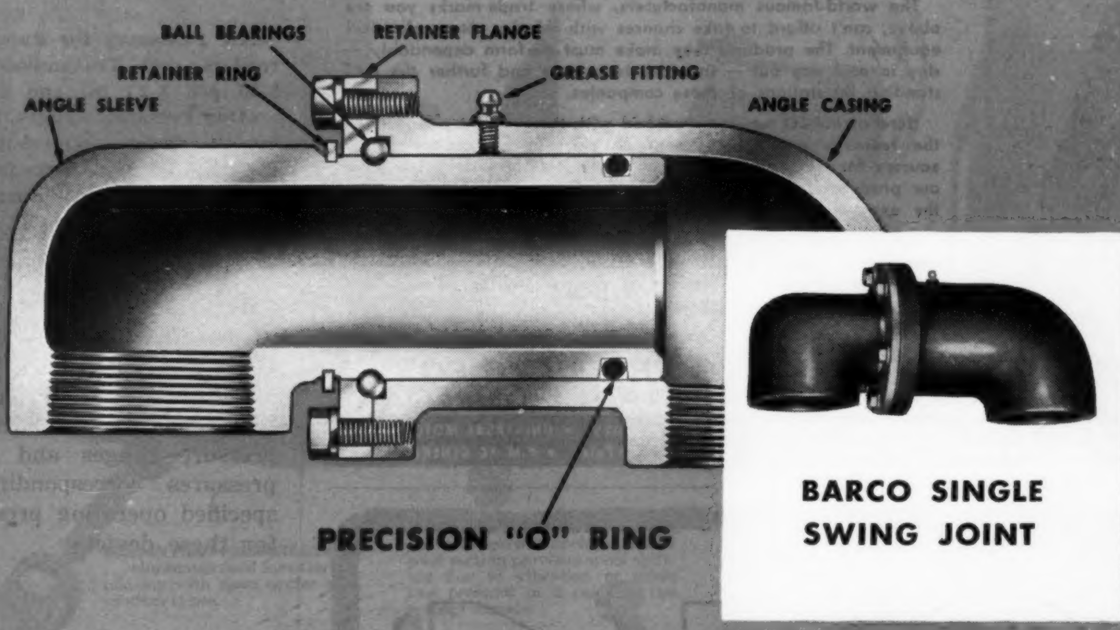

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beam deflections, continuous and restrained beams, properties of materials, simple bending, torsion, truss analysis, graphical methods, ties, columns, compression panels, buckling, combined stresses, connections, deflections by the dummy-unit-load method and an introduction to statically indeterminate structures.

New Standards

Air Pressures for Pneumatic Controllers and Transmission Systems 3-15 psi, 3-27 psi and 6-54 psi Operating Pressure Ranges. 3 *pages*, 8½ *by* 11 *inches, paperbound; copies available from Recorder-Controller Section, Scientific Apparatus Makers Association,* 522 *Fifth Ave., New York* 36, *N. Y.*

This tentative standard applies to pneumatic controllers, intelligence transmission systems, motor operators and positioning relays. It establishes standard operating pressure ranges and air supply pressures corresponding to the specified operating pressure spans for these devices.

Association Publications

Symposium on Porcelain Enamels and Ceramic Coatings as Engineering Materials. *ASTM Special Technical Publications No.* 153. 128 *pages*, 6 *by* 9 *inches, paperbound; available from the American Society for Testing Materials,* 1916 *Race St., Philadelphia* 3, *Pa.,* $2.50 *per copy.*

The contents of this booklet is comprised of a symposium of sixteen papers dealing with the diversified fields to which porcelain enamels and ceramic coatings are particularly adapted. This symposium was held at the 1953 ASTM Annual Meeting and was sponsored by Committee C-22 on Porcelain Enamel.

•

1953 Proceedings of the Instrument Society of America. 339 *pages*, 8½ *by* 11 *inches, ringbound, paper covered; copies available from the Instrument Society of America,* 1319

The Engineer's Library

Allegheny Ave., Pittsburgh 33, *Pa.,* $5.00 *each for ISA members,* $10.00 *each for nonmembers.*

This volume contains all 74 papers presented before the Eighth National Instrument Conference held in Chicago, September, 1953. Subjects covered include instrumentation for production processes and testing; instrument operation and maintenance; physical properties measurement; and aeronautical, transportation, medical, geophysical and process control instrumentation.

•

Methods of Reasoning. *By P. D. Scott,* 16 *pages,* 8½ *by* 11 *inches, paperbound; available from the Cleveland Engineering Society,* 2136 *E.* 19*th St., Cleveland* 15, *O.* $1.00 *per copy.*

Starting from the basic thought of what is reasoning, this booklet proceeds through steps covering concept of the sensed difficulty, techniques of establishing the problem and how to state the approach and method of arriving at sound solutions.

Manufacturers' Publications

B. F. Goodrich Multi-V Belts Engineering Handbook. 76 *pages,* 8½ *by* 11 *inches, wirebound, paper covered; available from The B. F. Goodrich Co., Industrial Products Division, Akron, Ohio, on company letterhead request.*

This handbook features a convenient guide to the design of standard and high-capacity V-belt drives. New horsepower rating tables closely approximate actual operating conditions and reflect the increased ability of modern belts. The tables cover speed ratings from 100 to 6000 feet per minute.

•

Forming and Bending Kaiser Aluminum. 270 *pages,* 5¼ *by* 8¼ *inches, clothbound; available from Technical Editor, Kaiser Aluminum & Chemical Sales Inc.,* 919 *North Michigan, Chi-*

The Engineer's Library

cago 11, Ill., on company letterhead request, or $2.00 per copy.

Covering practical procedures and technical advancements in forming and bending aluminum, this book presents comparative material on different types of forming equipment and offers design engineers specific data on aluminum characteristics. These data indicate aluminum alloys favorably suited to specific forming and bending operations.

Subjects considered in separate sections are: forming and bending with hydraulic and mechanical presses, forming aluminum in rubber, roll forming, spinning, bending pipe and tube, tensive and compressive forming, and a glossary of terms applying to metals and metalworking.

•

"Timing" Belt Drive Engineering Handbook. *By Richard Y. Case, engineer, United States Rubber Co., 201 pages, 5½ by 8½ inches, clothbound; available from United States Rubber Co., Rockefeller Center, New York 20, N. Y., or New York Belting and Packing Co., 1 Market St., Passaic, N. J., on company letterhead request.*

Written by the Timing belt inventor, this handbook provides the designer with all pertinent engineering data necessary for the incorporating of Timing belt drives in original equipment. Standard drive tables are included.

Government Publications

NACA Technical Series. *Each publication is 8 by 10½ inches, paperbound, side-stapled; copies available from National Advisory Committee for Aeronautics, 1924 F St. N.W., Washington 25, D. C.*

The following Technical Notes are available:

3212. **A Nonlinear Theory of Bending and Buckling of Thin Elastic Shallow Spherical Shells**—58 pages.

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3215. **Tests of Bonded and Riveted Sheet-Stringer Panels**—45 pages.

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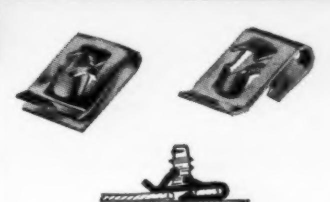

Self-retaining "U" and "J" Type SPEED NUTS hold themselves in screw-receiving positions for blind-location assembly. John Deere uses sturdy 14Z sheet metal screws, power-drives them into nuts—no pre-assembling! SPEED NUTS can't freeze on threads—screws are always easy to remove for servicing.

Write for your copy of "SAVINGS STORIES"—a volume filled with fastening ideas. TINNERMAN PRODUCTS, INC., Dept. 12, Box 6688, Cleveland 1, Ohio. *In Canada:* Dominion Fasteners Ltd., Hamilton, Ontario. *In Great Britain:* Simmonds Aerocessories, Ltd., Treforest, Wales. *In France:* Aerocessoires Simmonds, S. A., 7 rue Henri Barbusse, Levallois (Seine).

Stress Relief

WHEN a psychologist looks at today's engineer and concludes there's a "new engineer," it's something to look into. In a recent issue of GM's *Engineering Journal,* Dr. Louis J. Cantoni of General Motors Institute offered the following answer to this question:

What Is An Engineer?

A facetious definition which has been current is:

> An engineer is a person who passes as an exacting expert on the basis of being able to turn out infinite strings of incomprehensible formulae calculated with micrometric precision from vague assumptions which are based on debatable figures taken from inconclusive experiments carried out with instruments of problematical accuracy by persons of doubtful reliability and questionable mentality for the avowed purpose of annoying and confounding a hopeless and chimerical group of fanatics referred to, all too frequently, as engineers.

Many reactions are possible to this definition, and most of the reactions, after the first chuckle or two, are not favorable to the engineer. One reaction is that the definition is tragicomic. Comically, the engineer strikes one as a burlesque fellow whose jocular purpose in life is that of mystifying his colleagues. But tragically, in the pile-up of emasculating phrase upon emasculating phrase, the engineer emerges a man stripped of his singular achievement—his technical competence.

The definition, of course, represents a bit of humor and any one in as demanding an occupation as an engineer's should resort to humor occasionally, if only to maintain his sense of proportion. Perhaps travesty is healthy when it is a family affair. Yet, the joking of intimates can reflect the actual views of certain critically

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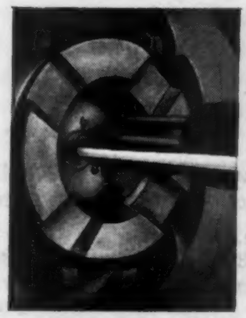
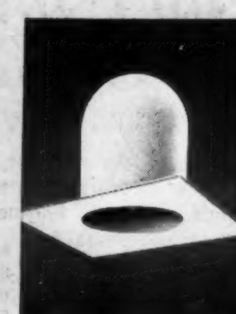


Extruded wire insulation

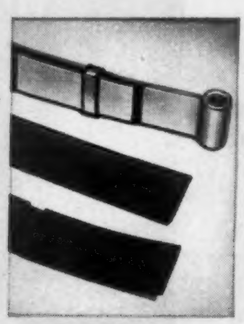
Blow-molded carboys



Vacuum-formed dome

REMEMBER THE MANY USEFUL PROPERTIES

- **Very light weight**
- **Flexibility**
- **Toughness**
- **Abrasion Resistance**
- **Chemical Resistance**
- **Translucency**
- **Colorability**



Auto spring pads

Pipe

Pipe thread protectors

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disposed groups. Some educators, some nonengineer management people, employees, and members of the general public entertain a stereotype of the engineer very much like the one quoted.

Why does the definition convey an impression unfavorable to the engineer?

It is not because of the humorous approach. The real reason is that the vitalizing influence of the human-relations emphasis has been omitted. Without this emphasis, the engineer's know-how is like a gasoline engine which does not power anything because it cannot be sparked into action.

In the nation's industrialized economy, everyone is the loser when a worthwhile new tool or method fails to be adopted in business or in industry. Yet, many new tools and methods fail to be put into use every day because some expert's approach to his colleagues or other workers did not include an understanding of their individual needs and desires.

The engineer has gained wide recognition for the technical competence which, as a matter of fact, he possesses by training and experience. Beyond this, he is gaining recognition for the human-relations understandings and skills which he has begun to build in. A survey of engineering-school catalogs will show that, since World War II, an increasing number of courses are being offered in humanistic studies and in the social sciences, specifically in psychology. In addition, through enrollment in adult-education programs, whether management-sponsored or not, the working engineer has demonstrated his growing interest in the human-relations aspect of his job.

What, then, is the new engineer? The new engineer E_N is the product of his own technical competence C_T in interaction with varied life experiences L_{VE} which have been energized by psychological insight I_P. Expressed as a formula:

$$E_N = I_P\ (L_{VE} + C_T)$$

Whether he is at home, at work,

or in the social and civic community, insight vitalizes the engineer's day-to-day experiences with people. Insight enables him to discover what is implied in their likes and dislikes, their special abilities and peculiar weaknesses, their desires, their ambitions, their attitudes, and the typical ways in which they attempt to stave off anxiety. As his varied and meaningful life experiences interact with his technical knowledge and skills, the engineer recognizes the importance of the human factor in his efforts to improve design, to employ better methods, to reduce cost, to step up quality, or to locate new markets.

Psychological insight does not operate in a hit-or-miss fashion. There is nothing strange about the fact that, on or off the job, people seek social approval and plan situations and events so that they can feel secure. However, when things do not turn out in accordance with their needs and desires, different individuals have different ways of maintaining their self esteem. The conscious and systematic application of psychological principles toward understanding people's reactions to stress and frustration very often affords insight into the reasons for their behavior.

But it is not enough for the engineer to try to understand the feelings and the motives of others. A growing understanding of others is dependent upon a growing understanding of one's self. As he applies his knowledge of psychological principles to himself, the engineer develops more and more insight into the why's and wherefore's of his own actions and reactions. This self-understanding, in turn, helps him to perceive with increasing accuracy the effects of his own behavior on the behavior of others around him.

In summary, the new engineer represents the fusion of his own meaningful personal experiences with his technical competence. Because of this fusion, he can work effectively with colleagues and others toward the solution of some of the world's multidimensional engineering problems.

NOTEWORTHY Patents

MISALIGNMENT COMPENSATION in rotating shaft connections is provided by a flexible coupling design. Employing a three-piece construction, the coupling consists of identical flanged hubs mounted to each shaft and a center torque transmitting disk molded of a flexible material. Torque is transmitted through the molded disk by means of projecting lugs attached to the flanges, which engage mating holes in the center disk. Assembly and maintenance are facilitated by the compact three-piece construction and the resilient center disk is capable of withstanding relatively high operating deflections and parallel or angular misalignment of the connected shafts. *Patent* 2,659,218 *assigned to Morse Chain Co. by E. F. Riopelle.*

REMOTE FLOW CONTROL in high-pressure hydraulic systems is offered by a solenoid valve employing a built-in pilot arrangement. Designed for normally-closed operation, the valve can handle large flow rates and is especially suited for use with panel board or other centralized control installations. Flow through the valve is controlled by a solenoid-operated, spring-loaded plunger which opens and closes a bypass leading to the rear of a spring-loaded main valve plunger. When the bypass is open (solenoid energized), fluid pressure actuates the main valve plunger to permit flow straight through the valve. When the bypass is closed (solenoid de-energized), or system fluid pressure drops below a prescribed minimum, spring action closes the main plunger to cut off flow. Valve operating forces are reduced to minimum by the design which provides instantaneous and positive electric control over flow-rates with a small lightweight valve assembly. *Patent* 2,663,319 *assigned to Bendix Aviation Corp. by J. Marinelli.*

REVERSIBLE BELT DRIVE for low horsepower applications combines a standard V-belt transmission with a friction reverse. Controlled by a lever-operated linkage, the drive offers three-way power control: forward, neutral and reverse. In the forward position, power is transmitted by means of the V-belt drive through sheaves on the driving and driven shafts. Adjustment of the control lever to the reverse position however, actuates a linkage to move the shafts closer together engaging friction drive disks on each of the shafts and reversing the direction of rotation of the driven shaft. At the same time the movement

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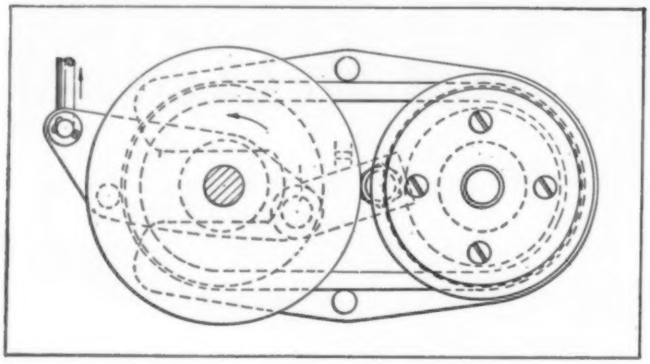
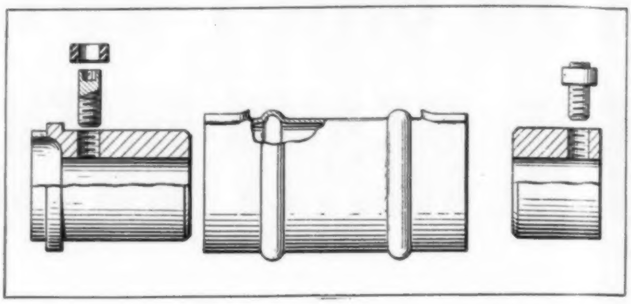
of the shafts loosens the V-belts on their sheaves to disengage the belt drive. In the neutral or intermediate position, both the friction and V-belt drives



are inoperative. Retention of the V-belts on the sheaves during neutral and reverse operations is provided by pin stops. *Patent 2,670,630 assigned to Reo Motors Inc. by W. E. Williams.*

VIBRATIONLESS TORQUE TRANSMISSION between connected shafts is offered by a flexible coupling design. Metal-to-metal contact between power transmitting members is eliminated by the design which is suitable for use under limited misalignment conditions and can be operated in either direction of

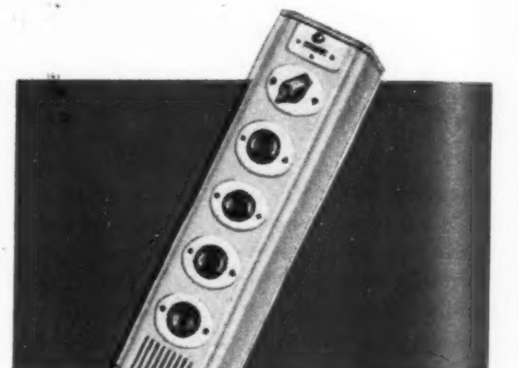


rotation. Power is transmitted from the driving to driven shaft through a metal sleeve which is slotted at the ends to engage projecting radial lugs or set screws on hubs mounted to each shaft. Metal-to-metal contact is prevented by the use of rubber bushings at the lugs and O-ring spacers between the hubs and sleeve. Resilience of the rubber acts as a cushion to absorb vibration but permits torque transmission without windup or surges. *Patent 2,667,768 assigned to Stewart-Warner Corp. by H. E. Winkler and M. F. Winkler.*

BACKLASH TAKEUP in spur gear trains is provided by a three gear assembly mounted as a single unit. Serving as an idler gear, the three gears of

DIAL THE SPEED—CONTROL THE PROCESS

with a Performance Rated© Century SELECTIVE SPEED DRIVE



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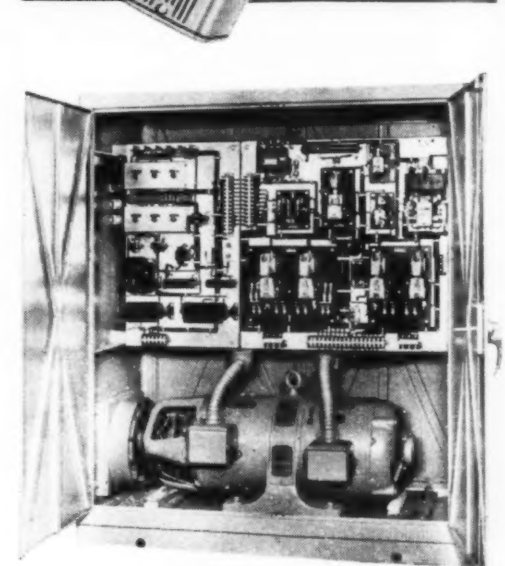

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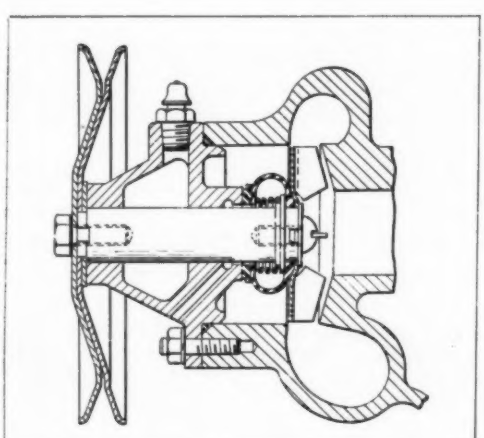
the assembly are mounted side by side on the same shaft; the center gear is fixed to the shaft while the outside gears are free to rotate or float and are connected by means of a wire spring which tends to turn them in opposite directions. Power is transmitted through the fixed gear. One floating gear meshes with the driving gear in the train and other floating gear with the driven gear. In operation, the spring action of the floating gears acts to apply pressure in opposite directions on the teeth of the mating gears, eliminating play between the gears of the train. A modification of the design for use in a reduction gear drive is also described in the patent. *Patent* 2,663,198 *assigned to Bendix Aviation Corp. by Charles W. Cairnes.*

LEAKTIGHT SEALING of shaft and housing assemblies to prevent contamination of hydraulic fluids in impeller pumps is effected by a molded rubber shaft seal. Sealing action is provided by a V-shaped diaphragm construction; one leg is mounted rigidly between two shoulder rings on the shaft and the other is bonded to a plastic wear ring which engages



and slides against the housing. Sealing engagement of the wear ring with the housing is maintained by a coil spring which is backed up against one of the retaining shoulder rings. Irregular shaft or housing end movements are accommodated by the flexible rubber diaphragm and the seal shape is such that variations in external hydraulic pressure will not affect the pressure of sealing engagement of the wear ring. Modifications of the seal for use with different housing and shaft mounting requirements are also shown. *Patent* 2,671,407 *assigned to Chrysler Corp. by Alan L. Higbie.*

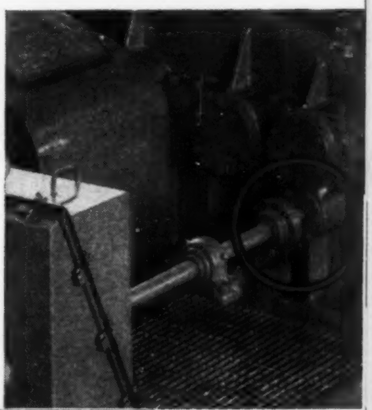
Copies of the patents briefed in this department may be obtained for 25 cents each from The Commissioner of Patents, Washington 25, D.C.

Amerigear HMC* COUPLINGS

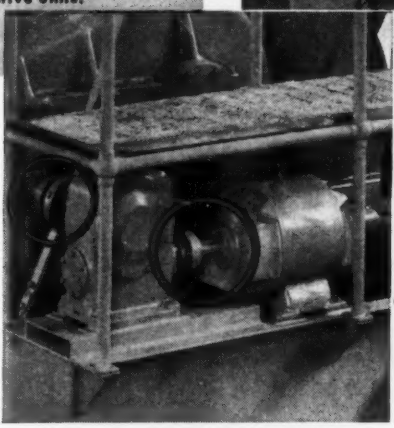
HELP TAME THE RIVER GIANTS...

transmitting power to raise and lower four 42 x 39 foot gates in fluctuating service at Big Cliff Dam

General view of gate hoist machinery used at Big Cliff Dam. Note relatively small size of Amerigear Couplings in comparison with the drive units.



Close-up of a portio of the gate hoist ma chinery, prior to in stallation. Hange bearings are placed a eight foot centers. Tw couplings are used o each shaft. Amerigea Coupling shown is on of several standar types available.



View of standard Am erigear Coupling pla ced between moto drive and speed redu cer and Cut-Out Typ Amerigear Coupling with Shifting Colla and lever betwee reducers.

Built for the purpose of re-regulating the fluctuating discharges effected by the "Detroit" Dam three miles upstream, the "Big Cliff" Dam is located on the North Santiam River in Oregon. One hundred eighty-two feet from foundation to deck, the Big Cliff Dam is controlled by four radial gates—no mean assignment against the forces of water roaring through the one hundred ninety-two foot ogee spillway, out of a nearly three-mile reservoir. Four triple-reduction, herringbone gear speed reducers, coupled with Amerigear HMC* Flexible Couplings do the job — fufilling every requirement for precise, positive operation. Designed to operate effectively under sustained heavy loading or intermittent shock loading, Amerigear HMC* Couplings minimize the effects of any lateral or angular misalignment that may occur. Thus, efficient transmission of power, with minimum wear or maintenance, is assured. Similar power transmission problems involving tight backlash requirements, space limitations or high speeds, can be solved with equal success by use of Amerigear HMC* Couplings.

HMC* stands for High Misalignment Capacity; engineered into *every* Amerigear Coupling.

Artist's conception of Big Cliff Dam on North Santiam Rivei Oregon. This 18,000 kilowatt project, and the Detroit Dam up stream, perform invaluable service in flood control, conserva tion and power production.

Photos, courtesy of U. S. Corps of Engineers, Portland Distric and Monarch Forge and Machine Works.

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New Machines

Materials Handling

Hydraulic-Lift Hand Truck: Shop Caddy hand truck has a hydraulic lift capable of raising loads up to 500 lb. Four-speed pump ram permits setting lifting speed according to the load. Lifting platform in the down position is at floor level; lifting height is 36 in. Platform is 16 x 20 in.; overall width, 23 in.; overall height, 50 in. *Precision Equipment Co., Chicago, Ill.*

Die Pullers: Units with capacities ranging from 5 to 50 tons are designed for use in automotive, aircraft and other stamping and forging plants using heavy presses. Hydraulic lift and hydraulic push-off permit inching action for accurate positioning of the platform and aligning of the die in the press. Each of two pusher arms can be operated independently or simultaneously to facilitate positioning. Upright design using hydraulic lift provides unobstructed forward visibility for operator. Platform is low as a result of the placement of pulling mechanism beside instead of underneath it. *Elwell-Parker Electric Co., Cleveland, O.*

Truck-Mounted Crane: Occupying 18 in. of space behind truck cab, Truck-Crane lifts up to 5000-lb loads onto truck or deposits loads within a 16-ft, 280-deg radius of the truck. Traveling carriage on boom spots loads. During unloading, hydraulically controlled outriggers stabilize the truck. Complete mechanism is hydraulic, with controls for boom, winch, carriage and outriggers operable from control panels on both sides of the truck. One hand lever reverses, locks or operates the winch at desired speed. Model HB-50 has horizontal boom with optional lengths up to 16 ft; model EB-50 has a telescoping elevating boom with extensions up to 22 ft. *Truck-Crane Inc., Chicago, Ill.*

Parts Feeder: Available in three sizes, the largest of which is 24 in. in diameter, Tumble Hopper feeds a variety of parts at a high rate. Production rate is variable by means of integral variable-speed drive. Typical parts fed by the machine are washers, nut blanks, nuts, special stampings and headed parts up to ½-in. in diameter. *Feedall Machine and Engineering Co., Willoughby, O.*

Metalworking

Tube Straightener: Operating at speeds from 60 to 240 fpm, model 1½ B modified tube straightener accommodates tubes of various lengths and from ½ to 3½ in. OD. Straightening process is either a completely automatic cycle of feed and delivery or is manually controlled. Unit employs five-roll principle of straightening in which a central pressure roll is located between two sets of opposed rolls, each set

having one driven and one idler roll. Entry table is a wood-lined, U-shaped trough, adjustable for height and incorporating an air-operated pusher carriage for feeding tubes. Pusher carriage is adjustable for various lengths. Exit table is an L-shaped trough, adjustable sideways as well as for height. *Sutton Engineering Co., Bellefonte, Pa.*

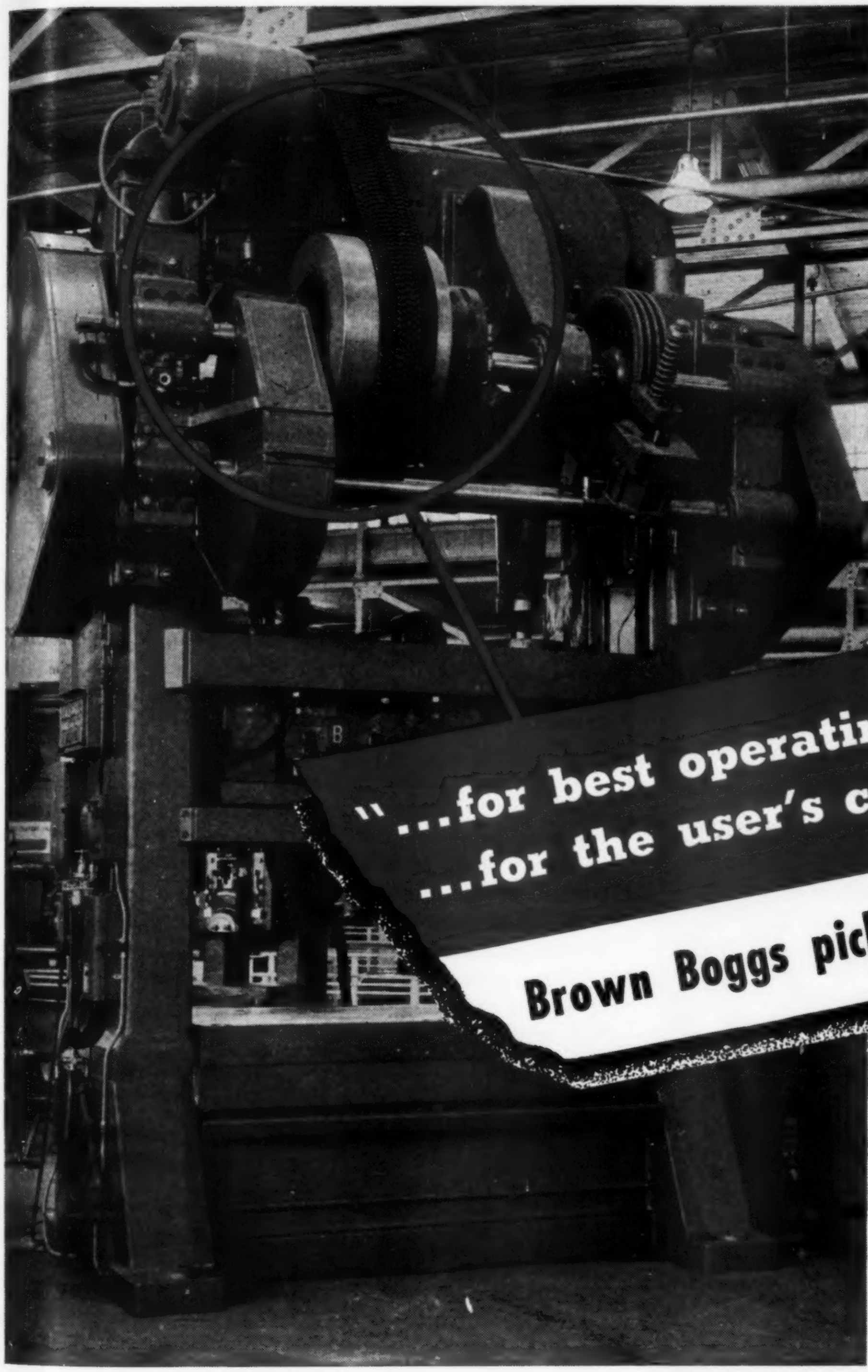
Precision Press: Power-Di one-ton press has $1\frac{1}{4}$-in. standard stroke, 3 to 6-in. shut height. It operates at the rate of 200 strokes per minute. Since punches and dies of any shape can be mounted in retainers which are automatically aligned in opposing ram and bolster members, die sets are not needed. Compact design makes possible setting several presses in series for simultaneous piercing, notching or forming operations on large sheets which otherwise would require use of larger dies and punch presses. Unit is available as a bench or pedestal press or an operational accessory for Swanson turret indexing units. *Swanson Tool & Machine Products Inc., Erie, Pa.*

Rotary Bending Machine: No. 800-2-in. bender makes both right and left-hand bends, with ample clearance for bends on more than one plane. Capacity is $2\frac{1}{2}$ in. OD x 0.065-in. wall steel tubing, or $1\frac{1}{2}$ in. standard pipe. Forward and reverse rotation of the bending arm is controlled by one hydraulic valve. Arm swings through an arc from zero position to approximately 190 deg, allowing 10 deg overtravel as compensation for spring-back on a finished 180-deg bend. Separate hydraulic valve controls mandrel movement. Bending head operates at approximately 8 rpm. Mandrel clearance is 102 in. Maximum radius adjustments are 10, 14, and 18 in. for $2\frac{1}{2}$, $1\frac{1}{2}$ and $1\frac{1}{4}$ in. OD maximum tube size. *Wallace Supplies Mfg. Co., Chicago, Ill.*

Resistance Solderers: Two Glo-Melt resistance soldering power units are rated at 500 and 1000 w. Both units are available for 115 and 230-v, 50 or 60-cycle power supply. Three-way output terminals, combined with a rotary switch, provide 24 different controlled heats for all types of precise resistance soldering. *Wassco Electric Products Corp., Joliet, Ill.*

Cylindrical Grinder: Designed for fast repetitive grinding as well as tool room work, machine has work capacity up to 4 in. diameter x 12 in. length; maximum recommended production grinding is $1\frac{1}{2}$ in. diameter. Workhead accommodates No. 1 Morse centers, both live and dead, as well as 4-in., three-jaw tapered draw-in chuck and quick-change collets up to $\frac{5}{8}$-in. capacity. Machine is equipped for both plunge and traverse feed grinding, with automatic infeed at the stops. Workhead speeds are variable from 125 to 610 rpm. *American Herforder Corp., Chicago, Ill.*

Jig Borer: Model 3E, a 13-ton machine, is designed for precision locating, boring, milling and checking. Electronically controlled milling feeds are infinitely variable from 1 to 15 in. per minute. Rapid power travel of 60 in. per minute is provided. Eight spindle feeds ranging from 0.0005 to 0.015-in. per spindle revolution, up or down, and 12 spindle speeds ranging from 30 to 1500 rpm are provided through a gear box



The Brown Boggs Foundry & Machine Company, Ltd., of Hamilton, Canada, who manufactures this 200-ton Press, thoroughly checked all types of v-belt. They wanted a v-belt that would give efficient, vibrationless, full power delivery. They wanted a v-belt that could be installed quickly and easily. Only Veelos met *both* requirements. And here's what Brown Boggs says about their selection of Veelos . . .

"...for best operating condition ...for the user's convenience"*

Brown Boggs picked Veelos v-belt

*"*We feel that our own factory assembly has put this Press in the best operating condition. To eliminate the necessity for dismantling any part of the equipment, and for the user's convenience in changing belts, we have equipped the drive with Veelos V-Belting.*"

Brown Boggs selected Veelos even though it cost more than ordinary v-belt. They know, however, that "what's best for their customer, is best for their business!" It will pay you to equip your machines with Veelos v-belt. Once you've done that you'll be an enthusiastic Veelos user, too.

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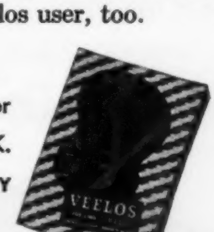


ADJUSTABLE TO ANY LENGTH • ADAPTABLE TO ANY DRIVE

and four-speed motor. Table is 28 x 56 in.; travel is 48 in. longitudinally and 28 in. transversely; maximum height between table and spindle end is 30 in. Columns 6, 10 or 14 in. higher than standard can be furnished. *Pratt & Whitney Div., Niles-Bement-Pond Co., West Hartford, Conn.*

Portable Power Saw: Guillotine type saw cuts 2 to 8-in. cast iron and steel pipe, as well as bar stock and beams. It operates in 25-in. wide space and clamps to the pipe, which serves as a base. Cut is made at right angle to the pipe. Saw weighs 120 lb. *E. H. Wachs Co., Chicago, Ill.*

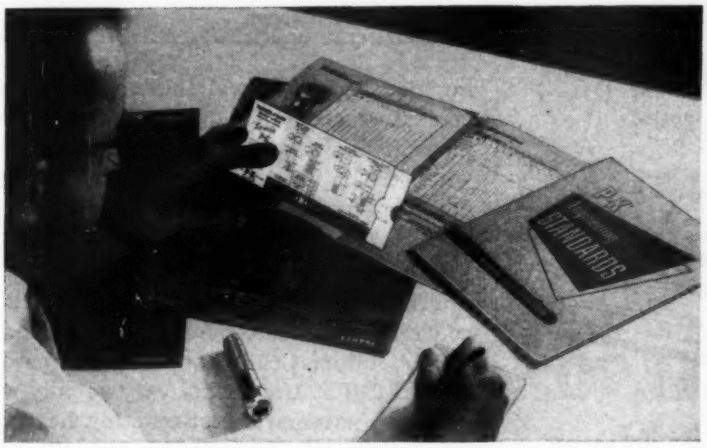
Internal Grinder: German-made Jung precision grinder for all internal cylindrical shapes is capable of high output. Table traverse is variable up to 120 strokes per minute, and interchangeable grinding spindles rotate at speed of 35,000 rpm. Dressing attachment permits plunge grinding of bullet, cartridge and similar dies and also grinds internal grooves of high-precision ball bearings. Machine can be furnished with face grinding attachment, with 75,000 rpm spindle and as a simplified machine for plunge grinding only. *Marac Machinery Corp., New York, N. Y.*

Welder: Available in 300, 400 and 500-amp NEMA-rated sizes, Fleetwelder Special is used for a wide range of ac production welding jobs. It is adaptable to sheet steel or heavy plate. Free-circuit reactor control of welding current is separate from the main transformer and can be adjusted continuously through a wide range of currents. Control is also sensitive to a wide range of welding conditions and is highly responsive to changing arc conditions. Frame, core and case of machine are welded steel; copper windings have spun glass, refined asbestos and mica insulation and mica coil separators. Current-control mechanism operates through a double-reduction gear drive with a ball bearing shaft. *Lincoln Electric Co., Cleveland, O.*

Flat Lapping Machine: Complete lapping of workpiece in a single pass around the lap is made possible by bonded abrasive laps over cast-iron laps in No. 36-F single-face Hyprolap. Semi-automatically fed machine operates continuously. Grit is washed away from work by a stream of filtered coolant on the lap. Lapping action is interrupted only to true the bonded abrasive lap, which is done by a diamond held in a variable-speed, power-operated truing arm. Truing speed is quickly adjusted. Machine can be arranged for fully automatic continuous-feed operation. *Norton Co., Worcester, Mass.*

Plant Equipment

Tank Type Filter: Kleenall filter combines a magnetic separator with a filtering area where the coolant passes through fabric. Fluid is first exposed to intense magnetic field by passing through a flow channel surrounding a rotating magnetic drum and then flows to the filtering area where it forms a pool on a supported fabric apron. Mechanical seal at the edges of the fabric permits formation of a pool of coolant up to 5 in. in depth. Fabrics of vary-



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ing densities are available to control the degree of coolant clarity. Rate of flow is controlled by a float mechanism which moves the fabric automatically when the liquid in the pool reaches a predetermined depth. Four models range in capacity from 15 to 60 gpm, based on water-soluble coolants. *Barnes Drill Co., Rockford, Ill.*

Temperature Control: Sterlco 6012 temperature control unit is suitable for applications requiring accurate, automatically controlled temperatures between 60 and 210 F. Unit heats very rapidly and has adjustable and automatic fast-reacting heating control, low water capacity, high water velocity and modulating cooling control. Typical uses include injection molding machines, vacuum forming operations and sheet extruders. Normally used in a vertical position, unit is designed to operate in four horizontal positions. *Sterling Inc., Milwaukee, Wis.*

Frequency Changers: Compact motor-generator frequency changers in 5, 7.5, 10 on 15-kw capacities convert 60-cycle current into a 180 or 360-cycle power source for operating high-cycle tools. Of two-bearing construction, units have motor rotor, exciter armature and revolving field mounted on a solid steel shaft which is dynamically balanced for quiet operation. Monitor top houses all motor and generator controls and instruments. Output voltage is little affected by voltage fluctuations in the incoming power supply. Regulation of output voltage is 3 per cent; frequency regulation is within 3 per cent. *Motor Generator Corp., Troy, O.*

Corrosive-Liquid Pumps: Centrifgual pumps designed especially for handling corrosive liquids can be furnished with a fluid end of stainless steel (three optional types), iron, bronze, bronze fitted, iron with stainless trim, or bronze with stainless trim. Nine sizes range from ¾ to 3 in., with capacities to 720 gpm and heads to 200 ft. Support is cast integral with the bearing housing. Temperature limitation for operation of the pump is 350 F, with provisions for water cooling of the support head and quenching of the gland. Single or double mechanical seals, which also can be quenched, are optional. Stuffing box is on the suction side of the impeller. Suction and discharge connections are in the casing. Standard position of the suction and discharge openings is vertical, but the casing can be swiveled 90 deg either way, to provide horizontal suction and discharge openings on either side. *Goulds Pumps Inc., Seneca Falls, N. Y.*

Processing

Injection Molding Machine: Designed to mold large parts, model 400-H-20 is a 20 to 28-oz machine and incorporates an automatic, compensating type weigh feeder. Injection unit, mounted on ways, is actuated by one hydraulic cylinder. Retraction, loading of injection nozzle and operation of positive sprue break are all hydraulically controlled. Dual injection pump permits two-speed or dual pressure injection and features a timed control which also permits reduction of injection pressure automatically after mold cavities

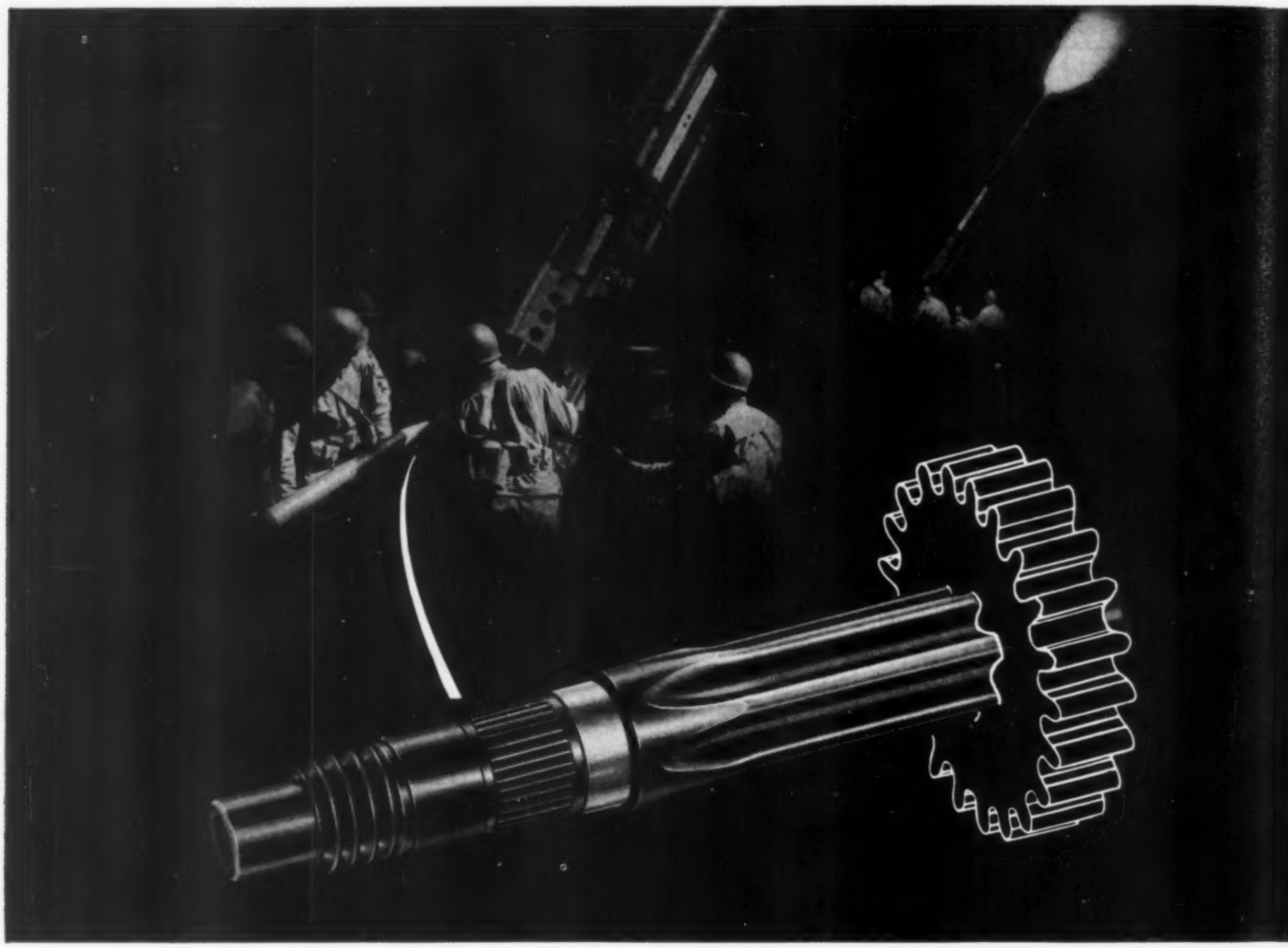
have been filled. Small, high-pressure axial piston pump is employed in the hydraulic circuit for developing maximum clamp pressure. High-capacity, double-vane pump operates the clamp and injection rams. Straight-line, hydraulic mold clamp provides fast closing and opening speeds with automatic adjustable slow-down prior to mold contact, at mold breakway and during ejection of the molded part. High-output plasticizing chamber is equipped with three pyrometer-controlled heat zones. *Hydraulic Press Mfg. Co., Mount Gilead, O.*

Electric Oven: Operations such as annealing of glass and nonferrous metals, baking, brazing, curing, heat treating, normalizing and soldering are performed by universal electric oven through the use of several banks of heaters which are controlled by a three-way selector switch for obtaining high, medium or low heat. A large volume of heated air is moved at high velocity about the work being treated. A 10-in. recirculating fan located in the top of the oven blows the air down past the heaters which are located in the side walls. Heated air enters the work chamber, rises vertically across work and is returned to the fan. Pyrometer type instruments control temperature automatically. Interior of oven and fan are stainless steel. Shelves are adjustable. Interior size of oven is 24 x 24 x 22 in. wide. Oven operates on either 220 or 440-v current. *Steiner-Ives Co., Union, N. J.*

Industrial Washing Machine: Drum cabinet model 30 x 20, designed to process steel stampings and machine parts, has a tumbling mesh drum for small stampings and a rocking cradle that will hold baskets of machined parts. Drum and baskets may be used alternately. Spray time is set by a timer, and the pump sprays detergent, followed by a clear rinse, at high pressure. Machine can be heated by gas or steam and is 4½ ft long, 4 ft wide and 7 ft high. *Industrial Washing Machine Corp., Matawan, N. J.*

Batch Type Ovens: Heavy-duty, convection type ovens can be either electric or gas-fired. Temperature uniformity throughout the work chamber is assured by system of air recirculation. Forced air penetrates to every part. Ovens are built for either horizontal air flow with heating elements located below work compartment, or vertical flow with heating elements in a plenum chamber in the rear. Air volume and positive exhaust and intake are adjustable. *Burdett Mfg. Co., Chicago, Ill.*

Balancing Machines: Horizontal static-dynamic balancing machines indicate unbalance automatically for the selected plane of correction by means of highly sensitive Electrodyne electronic indicating system. Angle and amount of unbalance are shown on two large meters in control panel. Plane of correction can be changed quickly with a pivot shifter which assures positive plane separation. Calibration of the indicating system can be checked or changed with a screwdriver, and full scale on the amount meter can be set to indicate any desired amount of unbalance. *Tinius Olsen Testing Machine Co., Willow Grove, Pa.*



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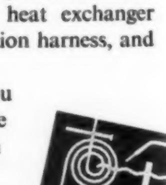

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